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Modern Science
II**

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ANCIENT TEXTILES MODERN SCIENCE II



Heather Hopkins
& Katrin Kania

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Edited by

Heather Hopkins and Katrin Kania

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Goldschmidt; Measuring of
indigo liquid for vat dyeing.
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Mainz, photo V. Iserhardt;
Hanging indigo-dyed textiles for
oxidation. Photo Julie Størup.

Back cover:

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Foreword

Michael Herdick

With pleasure I have the honour to write for the second time the foreword for a volume of selected papers from the European Textile Forum (ETF). In 2018, the textile archaeologists and craftsmen/women will meet for the seventh time at the Roman Germanic Central Museum's (RGZM) Laboratory for Experimental Archaeology (LEA) in Mayen. Thereby it is possible to see the scholarly success of this presentation format that started as a private initiative. The annual programme provides possibilities to pursue personal research interests and scholarly exchange of ideas, as well as learning new craft techniques. The contributions in this anthology give an impression of the technical level and the will to make the findings of the international scientific community accessible to all.

Furthermore, the success of the ETF is a confirmation of the Laboratory's concept of providing a research infrastructure as part of the Leibniz Gemeinschaft, where external, scholarly-oriented persons can carry out their research. The lab itself is part of the 'Kompetenzbereich Experimentelle Archäologie' of the RGZM and was officially opened in 2012. The in-house areas of expertise include ceramic kiln technology and the raw material design of the Mayen pottery industry, as well as non-ferrous metallurgy and craftsmanship. For the colleagues and guests of LEA, there are two well-equipped workshops including potter's wheels, smithy forges, electrical furnaces and diverse analytical equipment. Outside there are two custom-made shelters for long-term projects for reconstructed kilns and furnaces. In the case of workshops that run over several days, LEA has two sleeping quarters with a total of ten beds, as well as a separate seminar room at its disposal.

I can only hope that the ETF will continue to regularly report on the results of their work, with the same consciousness and attention to the quality that they have already shown to date.

Römisch-Germanisches Zentralmuseum
Leibniz-Research Institute for Archaeology
KB Experimental Archaeology and

Introduction

Heather Hopkins and Katrin Kania

We are delighted to introduce the second volume of proceedings for the European Textile Forum.

This book gives an insight into the wide variety of topics covered, discussed and explored during the week-long conference, which has grown into a yearly event. The European Textile Forum was originally developed around a large-scale spinning experiment which took place during the inaugural conference in 2009 in Eindhoven, Netherlands. After a few years of wandering, the ETF has found a steady home and a brilliant partner in the Laboratory for Experimental Archaeology in Mayen, where it was first hosted in 2012. Here, the generous support by the Römisch-Germanisches Zentralmuseum through LEA enables scholars, crafters and researchers from across Europe and around the world to get together and discuss, question and research historical textiles both in theory and in practice.

We hope that the articles published in this volume will be informative, helpful and inspiring to both those working on the theoretical and those working on the practical aspects of historical textile research. The ETF will continue to bring those parts together, hopefully for many years to come.

Chapter 1

On the terminology of non-woven textile structures and techniques, and why it matters

Ruth Gilbert

The terminology used with regard to looping, netting, knitting and other non-woven structures and techniques of textile manufacture is in general imprecise and can be confusing. In order to discuss these, including distinguishing clearly between them, it is essential to have a practical working vocabulary that describes the artefact and the way it is made. The aim of this paper is to provide a brief and referenced checklist for those concerned with the identification of artefacts. There are two major works on the subject of classification, one based on structure (Emery 1994) and one on technique (Seiler-Baldinger 1994); both give alternative terms from other authorities for comparison. The bibliography has been kept to a minimum, as the titles given will provide references for further reading on specific subjects.

The problem

Any one structure may be made in several ways, and one technique may produce many structures. The intention of this paper is to identify and name structures that are topologically identical. A topologist has been defined as a person who cannot tell a ring doughnut from a coffee mug, and in textiles this approach may require the lumping together of herring baskets and bobbin lace if they have the same structure. Specialists in basket making, lace making and other techniques have their own terminologies but there is a place for a description not dependent on the making process. The basic principle is: one structure or process, one term. Ambiguity is always a

problem and although many of these are unfamiliar terms, words only become familiar through use. For clarity, non-English words are *italicised* in the text and preferred terms appear in **bold**.

It is often the case that a surviving artefact constitutes the only record of its production: what can be seen and described is the structure, and the technique may or may not be deducible from that. The fragment in [Figure 1.1a](#) should not be described as plain weave, because the structure shown, which is **plain interlace**, can be produced by interworking one element (knotting, darning) as in [Figure 1.1b](#), a number of elements in one system (plaiting) as in [Figure 1.1c](#), or two sets of elements, loom weaving, as in [Figure 1.1d](#). The alignment of threads in the structure produced by plaiting is shown at 45° to the edge of the band, therefore called **plain oblique interlace**, but what bobbin lace makers call ‘cloth stitch’ is a one-set-of-elements plaited plain interlace made as though woven, with thread alignment parallel to the edges of the work. Without surviving selvages the orientation of a piece cannot be known. As a comment on the whole process of naming, no-one would ask a bobbin lace maker to call their structure ‘one-set-of-elements plain rectilinear interlace’, because for their purpose ‘cloth stitch’ is adequate, but other techniques must be borne in mind as possible before assuming that a scrap, or the imprint of a scrap on a pot or metal artefact, was made by weaving. For the purposes of this paper **weaving** is a **two-sets-of-elements technique with a fixed warp under tension and a mechanical means of separating the warp into sheds**. Any structure that can be made by weaving can also be made in some other way; loom weaving is a late addition to the textile crafts, favoured for speed in spite of the limitation of possibilities.

The obvious problem with the accurate description of textiles is the separation of product and process, often exacerbated by inadequate terminology and technical ignorance. However, there is another aspect, which is the intentions and prejudices of the person responsible for the description. An illustration is given in a recent article on Maori textiles, discussing a *kete* bag made of leaf strips:

The weave structure ... is accomplished, showing regular and complex pattern. Although Emery would refer to this textile structure as oblique interlacing, it bears no structural difference to her definition of weaving ... the term plaiting is misleading, and is based on aspects of technique ... rather than structure. (White *et al.* 2015, 219).

This paragraph, in an otherwise exemplary article, manages to

conflate technique and structure in a muddle of self-contradiction. The diagram of a complex twill oblique interlace rotated to look as though loom woven simply adds to the confusion. The item under consideration was presumably made by a process that the authors would recognise as plaiting rather than weaving (both of which are techniques, not structures, as their verbal form should indicate) and although the structure, a 2/2 twill, could be produced by loom weaving the pattern would be extremely difficult to replicate. It is possible that the authors' objection is based on an internalised idea of hierarchy, that weaving is somehow superior, perhaps less 'primitive', than plaiting.

Emery categorising by structure and Seiler-Baldinger categorising by technique both result in the same ordering from simple to complex, as does Amsden's analysis of techniques by the use of fixed points for tension (Amsden 1973, 15–21). This is not intended by those authors, or by this article, to indicate a process of development. It is unfortunate that primitive, meaning original or earliest, has become unusable because it is deemed to suggest a lack of skill or sophistication. In practice, the simpler the technology, the more freedom the worker has to vary what is done and the absence of restricting hardware such as loom and shuttle makes the work more dependent on the personal skill and inventiveness of the worker. As Nordland puts it:

If there has been a tendency to regard knotless netting as a basically primitive technique, reflecting a very low stage of development in the history of textiles, the analysis ... should be proof of the contrary ... a technique which presupposes not only fingers accustomed to the needle and thread, but also minds accustomed to dealing with matters which we, even with a whole array of symbols, find difficult to comprehend. (Nordland 1961, 30)

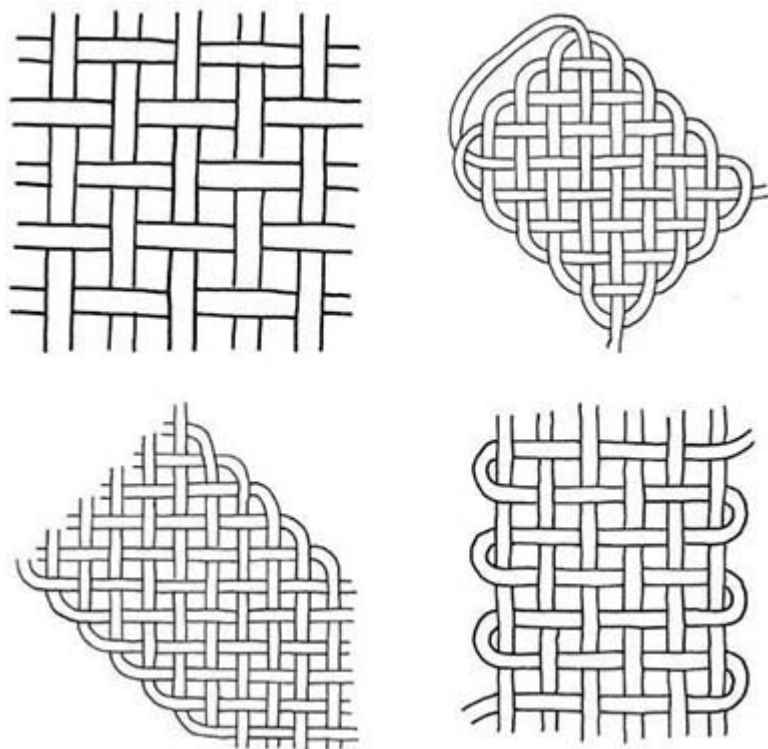


Fig. 1.1. a) Plain interlace, can be made in many ways; b) single element knotting or darning; c) one set of elements plaiting; d) two sets of elements, weaving. Redrawn by permission from Carey (2003, 7) (drawing: Sarah Thursfield)

For some techniques the possibilities of working direction, number and direction of interlacings, twists or loops and lateral connection are almost limitless and this article is by no means an exhaustive catalogue of either structures or techniques.

Approach to definitions

It is in practice impossible to separate the structures from the making processes, so both will be dealt with simultaneously. Reference must be made to some specific crafts: **bobbin lace making** (Earnshaw 1994) has been mentioned and constructional sewing and embroidery may use the same interworking of threads as fabric production, although usually supported by a passive fabric (Morrell; Eaton 1989). **Basket making** produces many structures the same as those in more flexible materials, usually made either by **interlacing** and **twining** free ends of one or more sets of elements or by **coiling**, which is

essentially a sewing technique (Emery 1994, 56). Baskets are never woven: the nature of the elements does not allow a fixed warp. Knots have no standard descriptive system (Ashley 1990, 10–12).

Making is an action, and words for techniques are therefore verb forms, whereas fabrics are things and their terms should be nouns, although these will require qualification. A structure should have a description separate both from the techniques used to produce it and from the fabrics in which it occurs; in this context a diagram is worth a thousand words. Good practice requires accurate description in words and in drawing, including indication of the working direction in diagrams where possible.

The starting point in an investigation of fabric structures is felt, which properly speaking has no structure, being a mass of disorganised fibres. **Felt** is made by **felting**, a mixture of chemical and mechanical processes. Bark cloth (*tapa* in the Pacific) is made by solely mechanical means and there are ‘non-woven’ synthetics such as interfacing fabrics that may be bonded by heat or chemical methods. Emery points out that bark cloth needs to be specified as **beaten bark cloth** to distinguish fabrics made from bark fibre yarn (Emery 1994, 21). Constructed fabrics may be treated by **fulling**, which is a similar process to felting, but they should be called **fulled** or **felted cloth** or fabric in preference to ‘woven felt’ or ‘knitted felt’. Apart from felt, fabric structures are made by interworking one or more elements.

Elements

The nature of the element has no bearing on the definition. An element may be a hazel branch in a hurdle, a bundle of grass in a mat or a spun yarn in a piece of cloth, and form the same part of the relevant structure. Elements may be used in their original form, for example withies or single horsehairs, but most are made specifically for a desired end. These **constructed elements** may be cut strips of hide, rag or metal foil; reeled silk; drawn wire; extruded synthetics; bundled short lengths replaced a few at a time, as in the passive element of coiled baskets; knotted short lengths, as raffia in Africa; short lengths **twisted** ‘between the hands or on a surface’ (Seiler-Baldinger 1994, 2) without drafting, as in much looping (West 2010, 30); or **spun yarn**. ‘Neither fibres nor filaments are properly termed *spun* unless the process of *drawing-out* ... is added to the twisting process’ (Emery 1994, 8, original italics). Spindle spinning appears to have been developed to maximise the storage, and therefore continuous length, of yarn as well as its quality. A twisted or spun

yarn may be **single** or **plied**, although the International Standards Organisation prefers **folded** (ISO 1139:1973). A subsequent twisting produces a **cabled** yarn (Fig. 1.2). These can be described using S and Z notation, in which the final diagonal is always the final, visible, twist. The difference between a single or plied yarn and **cordage** is a matter of size and purpose rather than structure; ship's hawsers may be constructed in the same way as sewing thread, but **rope** making has its own terms that should not be used elsewhere. An element may consist of one or many strands and may also be made by plaiting, interlooping or other processes, described as **compound constructed elements**.

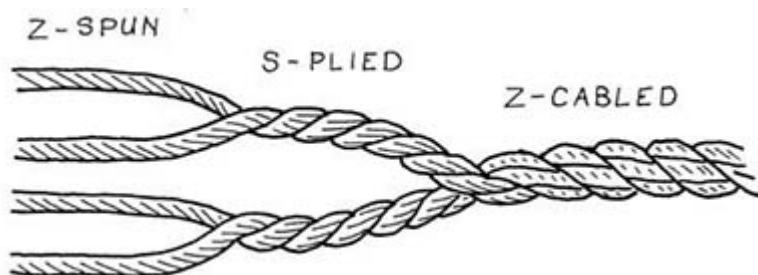


Fig. 1.2. Compound yarn Z4S2Z. Redrawn by permission from Walton and Eastwood (1988) (drawing: Sarah Thursfield)

‘The term ‘fabric’ comprises all the products of textile techniques that consist of basic elements ... which have been interworked by mechanical means’ (Seiler-Baldinger 1994, 5). The word **fabric** thus has to include everything from coiled bee skeps to wool broadcloth and punto in aria lace. Emery considers felt and beaten bark cloth to be fabric and it is hard to see why they should be excluded. Her next category is that of structures made with **one element** of limited length, one element used in preference to ‘single element’ to avoid confusion with the nature of the element itself. Here we come up against the problem of techniques/structure. As has been shown, the same structure can be produced in many ways, so this is surely classification by technique?

The distinction of length is important because some of these structures require the working end to be put through a loop, although some can also be produced with theoretically continuous or fixed end elements. In practice the working element is often joined (Collingwood 1998, 21; Claßen-Büttner 2015, 82) or added to (West 2010, 30) as the work proceeds, and joins may be identifiable in the fabric. The illustrations in this paper show the basic structure without

edges, because the edges will be different depending on the working method, as will the working direction. No attempt has been made to illustrate the course of one element through the fabric, although the diagrams are designed to encourage colouring in. The books cited offer variants and working methods, and the best way to understand the structures is to make them.

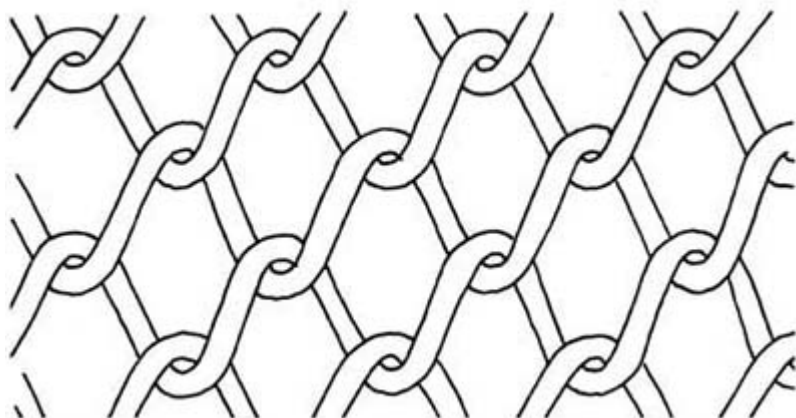


Fig. 1.3. Simple link. Shown oriented as produced by linking with one element with horizontal courses. When made by interlinking one set of elements the courses run vertically (drawing: Sarah Thursfield)

Simple link (Fig. 1.3) can be made by interworking a single element, although this technique is not as common as its simplicity might suggest. It is unsuitable for fishing and hunting nets, because the meshes can be easily opened out due to the lack of constriction where the elements link, although twists can be added to improve stability. Linking with one element is not easily worked into a dense fabric; dense simple link fabrics are made by a multiple-element technique.

The most widespread and varied one-element technique is **looping**, which can produce an immense range of structures. Of these the commonest are simple loop (Fig. 1.4a), **loop-and-twist** (Fig. 1.4b) and **hourglass loop** (Fig. 1.4c), known from the Middle East around 8000 BCE (Claßen-Büttner 2015, 30–32) and across the world (Collingwood 1998,14–19; West 2010, 64–73). Worldwide, simple loop is the commonest form, as both open and dense fabrics. Buttonhole or blanket stitch is simple loop supported by fabric (Morrell nd, 19) and detached buttonhole stitch is simple loop (Eaton 1989, 116; Emery 1994, 242). Supported looping requires another element.

Seiler-Baldinger's **hourglass** is more descriptive than Emery's

‘figure 8’, for the **laterally interconnected** structure in Figure 1.4c, in which the working end penetrates not only a loop of the previous course but also the previous loop of the same course. The names used for looping techniques are mostly useless as descriptors: ‘knotless netting’ and ‘single-needle knitting’ need to be discarded, as does the indiscriminate use of the Norwegian word *nålebinding*. The Scandinavian looping tradition is one of the best-known and Hansen defines *nålebinding* thus: ‘where the material is produced ... with a needle, and where the thread of the new stitch is passed arbitrarily through at least two unfinished thread-loops’ (Hansen 1991, 21). He distinguishes a technique of interconnected looping for dense fabrics quite different from the open mesh fabrics of Australia and New Guinea (McKenzie 1998; West 2010) and from the encircled looping of Romano-Egyptian socks (Burnham 1972). Simple loop was also common in Scandinavia, but is not as widely known (Nordland 1961, 19). It is possible to work looping without a needle if the end of the element is stiff but the complexity of the Scandinavian interworked structures makes a needle necessary. Both Nordland and Hansen propose systems for recording looped fabrics, of which Hansen’s is the more useful. The use of place names to identify structures or techniques is problematic and should be accompanied by a technical description, but in discussion ‘Oslo stitch’ is a great deal easier than UO/UO O (Claßen-Büttner 2015, 13–14, 64). Piening (this volume) discusses the difficulties and proposes a logical notation based on Hansen’s that can be used for more forms.

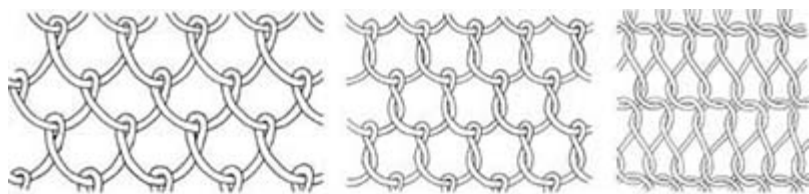


Fig. 1.4. Common looped structures: a) simple loop; b) loop-and-twist; c) hourglass loop (drawing: Sarah Thursfield)

The majority of looped structures must be made by putting the end of the working element through a loop. The exception to this is **encircled loop**, which can be made as a fabric by looping and in embroidery is called Ceylon stitch, ‘knitting stitch’ being a different structure (Eaton 1989, 113, 131). When made with a needle and finite length it is usually crossed (Fig. 1.5a) but when made as the commonest form of knitted fabric by **interlooping**, that is, **pulling a**

loop of the working element through the loop of the previous course, it is usually but not necessarily uncrossed (Fig. 1.5b). Emery proposes ‘plain knitting’ for this structure as a parallel with **plain weave**, but this is both verbal and ambiguous. The most useful current term is **stockinet** (Rutt 1987, 12). Unless the technique is known, the description of this structure should not refer to knitting (d’Harcourt 1987, 19, 104). Encircled loop, apparently needle-made, was used for a 3000-year-old cap found in a grave in the Tarim Basin in northern China (Claßen-Büttner 2015, 33), for socks in Egypt in antiquity (Burnham 1972, 116), as a decorative edging in pre-Inca Peruvian textiles (d’Harcourt 1987, 169 *et seq.*), in modern Nigeria (Collingwood 1998, 22–23) and New Guinea (MacKenzie 1998, 51). The use of a place-name as a descriptor is therefore to be discouraged.

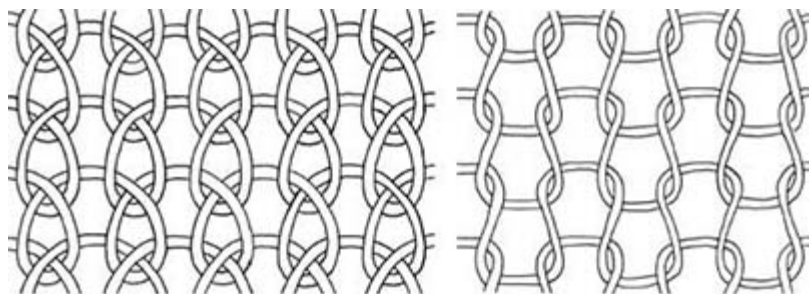


Fig. 1.5. Encircled loop: a) crossed, working direction downwards; b) uncrossed, working direction upwards (drawing: Sarah Thursfield)

Before moving on to interlooping, done with one element that is theoretically continuous, there is one more major one-element technique to consider, and a byway of looping must be mentioned first. Examples exist of **looped wire**, usually as a chain in jewellery, which is sometimes called ‘Trichinopoly work’ or ‘Viking knitting’. Normally a four-wale tube of vertical interlooping, it is difficult to tell from **loop-in-loop chain** (Fig. 1.6a) and identifications should be treated with caution. The decorative additions to the eighth-century Derrynalfan paten (National Museum, Dublin 1980, 4) appear to be of this structure but two panels from the base of the Ardagh Chalice (National Museum, Dublin, NM 1874:99) are in different complex encircled loop structures in silver and copper wire. These two artefacts may originate from the same workshop, but it is possible that the wire panels came from elsewhere. While on the subject of wire, mail shirts and loop-in-loop chain are made from interlinked closed loops and their structures cannot be replicated in yarn or cordage (Fig. 1.6).

Figure 1.1 includes an interlaced one-element structure, a knot.

What are generally referred to as ‘knots’ include **knots** where one element is interworked with itself, **hitches** where one element is interworked around another object, and two-element **bends** (Ashley 1973, 12). A one-element knot can be large enough to qualify as fabric, although this is rare (d’Harcourt 1987, 17, 149; Ashley 1990, 368–369). Knots may be added to secure a mesh made with one finite element the end of which is put through a loop, a technique that is ancient (Rast-Eicher 1992, 16) and universal (Dendel 1974, 154; d’Harcourt 1987, 105–107; West 2010, 33–34). **Knotted net** (Fig. 1.7) is used for hunting and fishing nets although the knot used may differ (Ashley 1990, 64; Emery 1994, 34–39). A shuttle is usually used to allow a longer yarn. **Knotting nets** in English is locally called ‘braiding’ and was called ‘knitting’ before the introduction of what is more generally understood by that term.

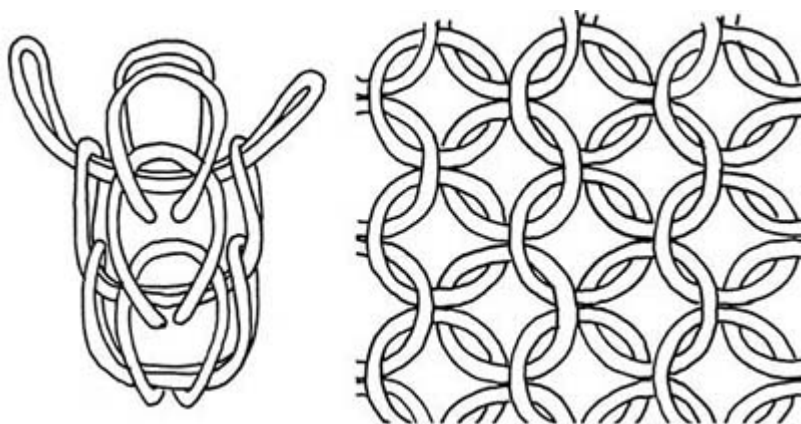


Fig. 1.6. Closed loop structures only possible in wire: a) loop-in-loop chain; b) mail (drawing: Sarah Thursfield)

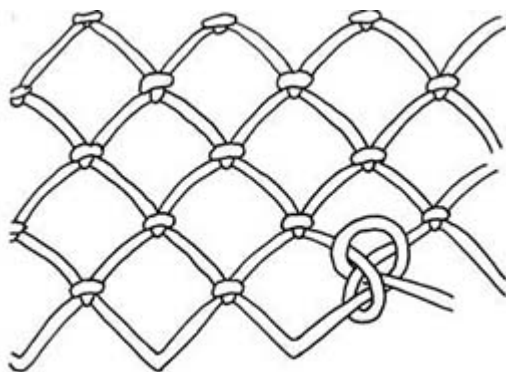


Fig. 1.7. Knotted net. A variety of knots may be used (drawing: Sarah

If the one element used is theoretically endless, it forms structures in which loops are always and only penetrated by other loops. Emery describes knitting as ‘single element vertical interlooping’, which is an adequate description of **stockinet** (uncrossed encircled loop, Fig. 1.5b), and other simple knitted fabrics, but does not allow for colour patterns, openwork, twined knitting, helical stripes and all the other complex structures that can be made. **Vertical interlooping** implies no lateral interworking of loops. If one element is interlooped vertically only with itself, without a foundation of laterally interworked **casting on**, it forms a chain of loops usually called ‘crochet chain’ (Fig. 1.8a). There are various forms of ‘finger knitting’ and square and tubular cords made with a lucet (Fig. 1.8b) or a knitting bobbin using one or two elements (Ashley 1990, 472–478; Carey 2003, 16–19). Ashley calls these ‘chain sinnets’ and if made by knitting in rounds on needles the current name is ‘I cord’ (Zimmerman 2006, 105). **Interlooped cord** is consistent and can be described by the number of **wales**, that is, columns of loops.

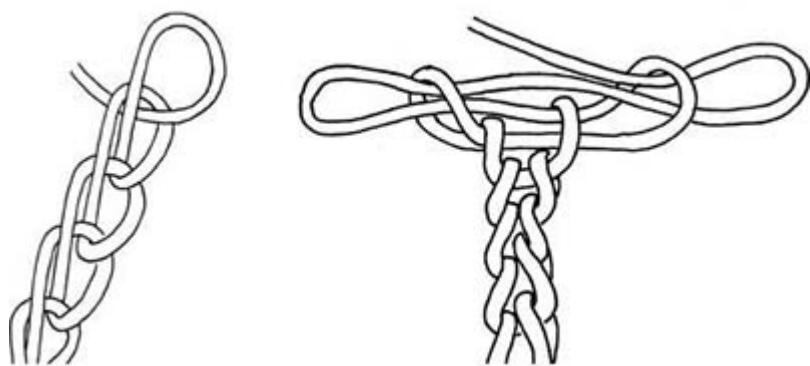


Fig. 1.8. Vertical interlooping: a) one wale; b) two wales (drawing: Sarah Thursfield)

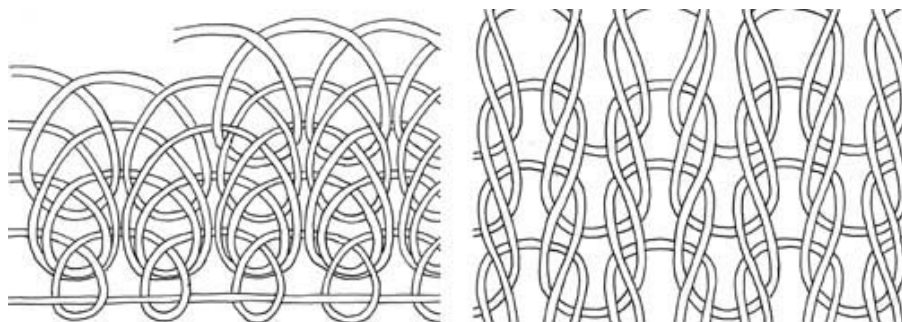


Fig. 1.9. a) Crossed compound encircled loop; b) uncrossed compound encircled loop (drawing: Sarah Thursfield)

A less common but historically widespread structure is **compound encircled loop**. Some identified examples are crossed and clearly made by looping with a needle (Fig. 1.9a). Rutt identifies several Chinese scraps from the third century BCE as comparable to one found in 2nd century CE context in the Netherlands, and uncrossed examples (Fig. 1.9b) include unpublished Romano-Egyptian tubular girdles, one of the looped wire panels on the 8th-century Ardagh Chalice and several scraps of multicoloured fabric from early medieval Egypt (Rutt 1991). The technique used for the uncrossed pieces apart from the wire is presumed to be knitting, either on a spool in the case of the girdles or on needles for the later examples, because the colour changes cannot be reproduced by looping (Harma Piening pers. comm. Nov. 2015). The Ardagh panel, in silver and bronze wire, was probably made by establishing a single structure in one kind of wire and then doubling it with the other (Whitfield 2018).

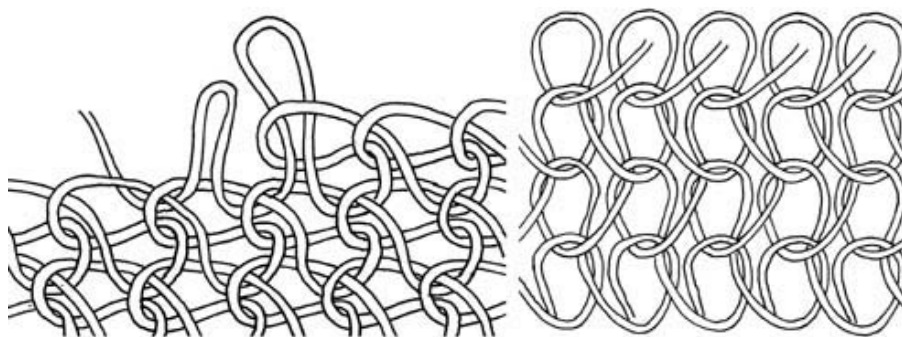


Fig. 1.10. Vertical and horizontal interlooping: a) slip crochet; the common form is worked as shown but the new loop may be drawn through the other shank of the loop in the previous course, allowing patterns to be made in the same way as with face and reverse loops in knitting; b) simple warp knitted fabric (drawing: Sarah Thursfield)

Crochet is one element vertical and horizontal interlooping, as are the usual ways of casting on and off in knitting (Rutt 1987, 10, 13–14). The commonest form of crochet around the world is what used to be called ‘shepherd’s knitting’ in Britain (Paludan 1995, 14–18; Collingwood 1998, 34–39). This is sometimes called ‘Bosnian’ and in England is often called ‘single’ crochet. The descriptive term should perhaps be simple crochet, but Paludan’s translator uses the satisfactory **slip crochet** (Fig. 1.10a), since ‘single’ has a different

meaning to UK and US workers. In its relatively short career crochet has been developed to produce a huge range of structures. There is also the knit-and-crochet hybrid that one 19th century book calls ‘idiot stitch’, and should be called by its early name, **tricot crochet**, not ‘Tunisian’, since it has no apparent connection with Tunisia (Rutt 1987, 10).

Structures with more than one element start with the addition of a **passive element**. **Coiled baskets** are wrapped, linked or looped over a passive element, usually a bundle of fibres, to make a rigid structure (Amsden 1973, 5; Seiler-Baldinger 1994, 33–36). Wrapping, by definition, cannot exist as a one-element structure, and Emery discusses its use in fabric construction (Emery 1994, 54–55). **Punto in aria** lace and **tatting** are both made by one element simple looping over a support thread (Earnshaw 1994, 38, 140).

Techniques using multiple elements in a single system begin again with a simple link structure (Fig. 1.3). This may be worked with free ends but the commonest form is made by interworking fixed elements, often a single length wound around a frame. The Swedish term *sprang* has become the accepted international word for this technique, which Collingwood (1998) calls ‘manipulating a set of taut threads’ (see also Emery 1994, 69). Elements are interlinked, interlaced and intertwined and the fabric builds up from both ends towards the centre.

A structure needs to be mentioned that appears in neither Emery nor Seiler-Baldinger’s books because it is only produced industrially, but it has been in use for about 150 years and can be hard to identify. It is **one-set-of-elements vertical and horizontal interlooping** (Fig. 1.10b) called **warp knitting** (Rutt 1987, 10) and is the basis of much industrially-produced knit fabric. The elements are not strictly speaking a warp, and in contrast knitting proper is referred to in industry as ‘weft knitting’.

The next category Emery calls ‘Oblique interlacing (Braiding)’ (Emery 1994, 60). Here the terminology becomes entangled, and **plaiting** is used in preference, because in UK usage ‘braid’ has too many vague meanings. Seiler-Baldinger uses ‘plaiting’, although her descriptions are confusing, probably due to the complexity of translation (Seiler-Baldinger 37–39). Structures consisting of **interlaced elements in one system** are very common, starting with a three-element free end plait. Free end plaiting can be used to produce flat cords, round cords, zigzag cords, plain and twill oblique interlace, openwork fabrics (Dendel 1974, 54–62; Collingwood 1998, 52), semi-rigid mats (Dendel 1975, 105) and baskets (Collingwood 1998, 58–59).

Complex plaits can be made in the hand but some form of support, sometimes a stand or pillow, helps to regulate tension and many traditions use bobbins to allow longer elements. ‘Assumption’ sashes (Atwater 1973, 67), bobbin lace (Earnshaw 1994, 61–69), hair work (Carey 2003, 34) and *Kumihimo* (Carey 2003, 38–39), are all forms of free end plaiting. **Two-layered oblique interlace** can be made by plaiting (Atwater 1973, 62, 68) or by ply-splitting (Collingwood 1998, 69). **Triaxial interlace** (Fig. 1.11) made using a single system of elements is the usual structure of cane chair seats. When used for baskets this structure may be made with three sets of elements (Collingwood 1998, 132–133).

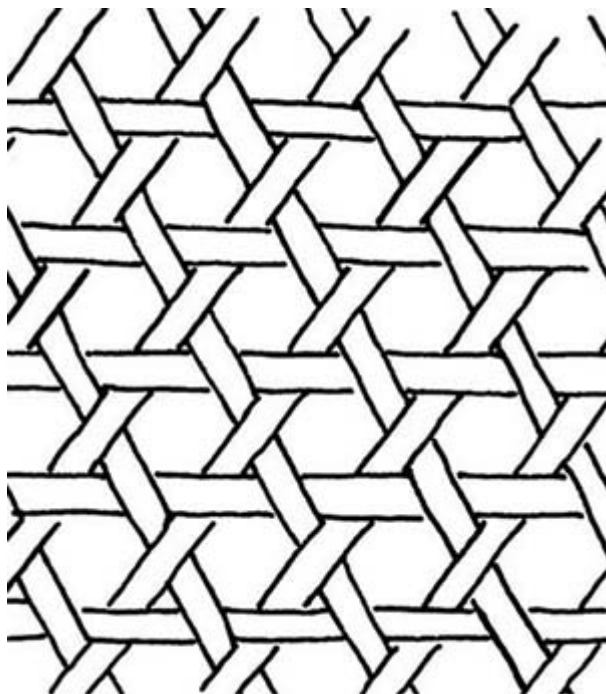


Fig. 1.11. Triaxial interlace commonly made with one set of elements for cane chair seats (drawing: Sarah Thursfield)

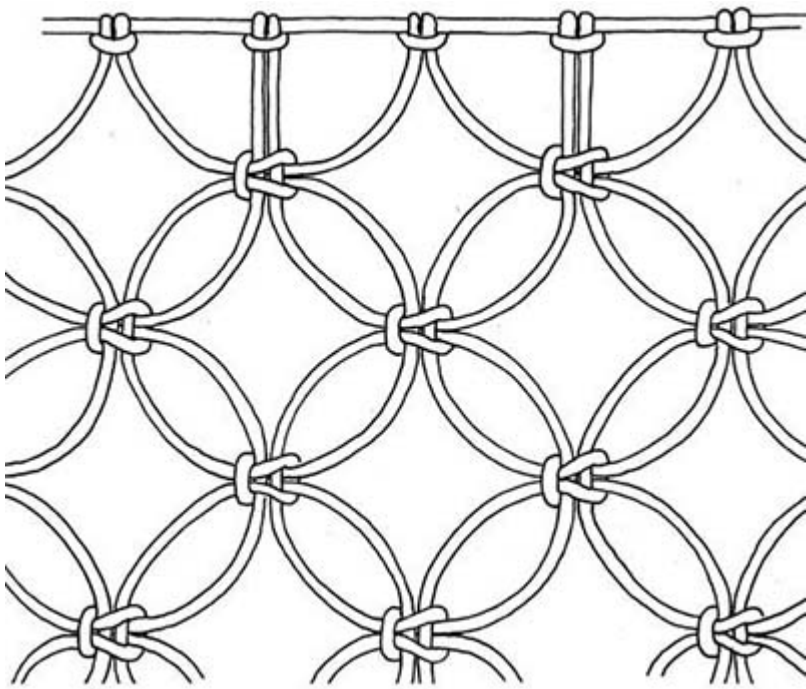


Fig. 1.12. Interknotted mesh with square, 'reef \ knots (drawing: Sarah Thursfield)

Many of the structures made by free end plaiting can also be made as cords or flat braids by **loop manipulation** (Carey 2003, 45). This should not be called 'finger loop' braiding, as that causes confusion with 'finger knitting', and the loops may be around the hands. Unlike free end plaiting, loop manipulation is sometimes worked with a second system, a **weft element** that is not part of the tensioned set, to produce **twined** structures (Collingwood 1998, 146).

Interknotted, often called 'macramé' and made with one set of elements, is mostly used for fringes and decorative work. Different knots, close or widely spaced, produce very different fabrics (d'Harcourt 1987, pls 72, 73; Ashley 1990, 584–585; Carey 2003, 14–15). [Figure 1.12](#) shows a square knot structure commonly used for string bags. It is possible to make a structure identical to knotted net with a set of elements rather than one, but the edges will be different and the courses will run vertically in relation to the knots, rather than horizontally (Dendel 1975, 157).

Oblique twined structures are made with one set of elements. The structure depends on the relationship of active and passive elements (Seiler-Baldinger 1994, 41–43) and [Figure 1.13a](#) shows **active-active**

oblique twining. Much ply-splitting produces oblique twined structures (Collingwood 1998, 60–68; Carey 2003, 50–51).

Structures made with two sets of elements, apart from weaving, include interlaced baskets and **twined** and **wrapped** structures. When made with two sets of elements, wrapping is usually done with a supplementary weft on a fixed warp and is therefore a weaving technique (Emery 1994, 213 *et seq.*). What is called **weft twining** is much older than loom weaving (Rast-Eicher 13, 16) and is easier to do with a free than a fixed warp (Atwater 1973, 43–55). It is hand manipulated using two sets of elements, a passive ‘warp’ with free ends, twined with elements of a second system (Fig. 1.13b). The number of warp ends interworked varies and two or more weft elements may be used. The structure may be open or very dense and is used for baskets (Hawkins 1978, 26–27; Collingwood 1998, 76), mats (Collingwood 1998, 72–73), decorative fabrics including Maori *taniko* (Atwater 1973, 43–46), the dance robes of the Chilkat (Hawkins 1998, 14–15), and even shoes (d’Harcourt 1987, 65; Collingwood 1998, 49–50). *Taniko* is normally worked in the hand, but the Chilkat work is done on a frame that Hawkins describes as a ‘warp-weighted loom’; it is not: the warp is not under tension, and there is no form of mechanism for shedding (Hawkins 1998, 14).

The same structures can be made by **warp twining**, either with a free or a fixed warp. Ply splitting is usually made with one set of elements but may also be made with a separate weft as **ply-split darning** (Carey 2003, 52–55), a warp-twined structure. That is made in the hand, and warp twine can be hand manipulated (Collingwood 99, 146) but the best known warp twining technique is **tablet weaving**, called ‘card weaving’ in the US (Carey 2003, 26–29). Tablet weaving can make many structures and may have been part of the development of true weaving.

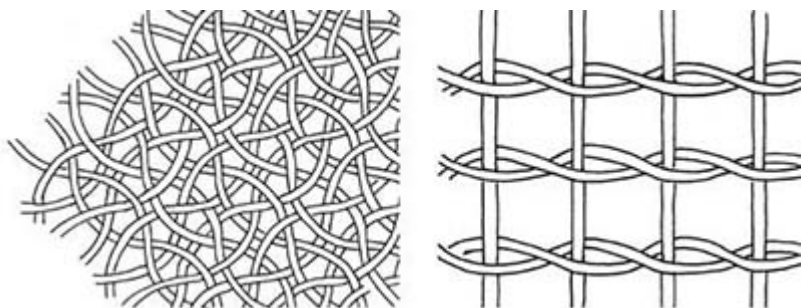


Fig. 1.13. a) Active-active oblique twine, one set of elements; b) active-passive twine, two sets of elements, shown oriented as produced by weft

Conclusion

And why does it matter? These 'primitive' techniques have enormous possibilities, not only decorative but structural as in gridshell buildings (Weald and Downland Museum) and can be very beautiful. They are neglected largely through ignorance, but also probably because the degree of manual skill required takes time and effort to acquire. Writing of a basket in simple link coiling Collingwood says:

This small basket with its accurately fitting lid gives me the feeling of awe that I often find overwhelming in an ethnographic collection. There should be another word for this superb sort of artefact; it is so many worlds away from anything made today under the name of craft (Collingwood 1998, 42).

We wish to talk about these things and to understand them, their makers, and the nature of societies that not only allow but encourage such skill. To do that we need to understand each other. Words are tools for communication, and good tools make work easier.

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Chapter 2

A new notation system for nålbinding stitches

Harma Piening

Nålbinding is a technique in which a stretchy fabric is constructed by interlinking loops of yarn. In contrast to knitting and crochet, nålbinding is created with relatively short lengths of yarn. This yarn is threaded through a needle with which the loops are ‘sewn’ together. It is mostly worked in the round or as a spiral. The technique is historically mostly used for making socks, hats and mittens but is also found in milk sieves.

Nålbinding has been practised from, at least, the early Iron Age and was common during the early Middle Ages. During this period it evolved from basic stitches in which only a few loops were interlinked to more complex stitches, which can include twisted turns or complex joining techniques. After the 13th century it was slowly replaced by knitting and only stayed in use in rural communities in Scandinavia and the Baltic States. Up until a century ago a man with knitted gloves was considered to have a lazy wife in some of those countries as nålbinding was viewed as superior (Pihlajapiha 2010–2016a online: Eesti Instituut).

During the 20th century nålbinding was rediscovered by archaeologists and ethnographers, who tried to describe and analyse the different stitches. By that time different names were used, such as ‘looped needle netting’ (Hald 1980), ‘one needle knitting’, ‘knotless netting’ (Schmitt 2000), ‘Coptic knitting’ (Burnham 1970) and even ‘Arabic knitting’ (Compton 1988). Even now the spelling of the most often used term, nålbinding, is not standardised, although most people prefer one of the variations of this term.

Naming the technique is not the only problem. Defining the stitch pattern and differentiating between stitches is difficult too, since there

are many variations possible. In the documented historical examples of nålbinding, the number of loops that are interlinked within a row can vary from none to nine (Hald 1980, 295), and interlinking can be done in different patterns. Additionally, the loops can be twisted, used out of sequence, or even be used more than once. Even the way in which the rows are joined together can give different effects with either compact structures, lace-like effects or with ridges on the front or on the back of the fabric.

There is yet no single notation system that covers all of these possibilities, leading to great difficulties in defining and describing nålbinding stitch patterns. Modern day nålbinders mostly use names for individual stitch patterns, often based on the place where a given stitch pattern has been found. This leads to names like ‘Oslo stitch’, ‘Finnish stitch’, ‘Omani stitch’ or ‘Åsle stitch’. A good example of this system in use is the book about socks by Larry Schmitt (2000). This naming of stitches can be very effective, since names are easy to remember, but does not solve the problem of describing stitches. For example, linking two loops can create at least 20 different stitches that would need to be described individually. Of those, however, only three have a name. The number of possibilities increases exponentially with the number of interlinked loops, with only a tiny fraction of the possibilities known from surviving textiles and named accordingly.

In Finland, stitches are described differing between three basic techniques: Finnish, Russian and ‘with a turn’. Within these three techniques, stitches are defined by counting the number of loops used in the same manner. (Pihlajapiha, 2010–2016b online) This notation is not efficient enough for notating more complex stitch patterns in which loops are used out of sequence or used more than once in the same stitch, because one needs extra information to identify all those different possibilities.

In addition to these informal ways of defining nålbinding stitch patterns, several scholars have created notation systems for nålbinding stitches. These are used both in academic articles about nålbinding and in more popular instructional texts.

The earliest attempt at defining and describing stitches in English was done by Odd Nordland (Nordland 1961 cited in Decker 2000a online). The notation is based on the concept that only the first quadrant of a stitch needs description, because every stitch forms a circle. However, there are many stitches that are asymmetrical, and at least half of this circle needs to be described.

Margrethe Hald (1980) created a notation based on the number of adjacent loops interlinked within a single row. In doing so she

excluded all variations in which fabric is created without this interlinking of loops. Within Hald's classification, all stitches in which the loops interlink with one loop on each side are called Type I, distinguished from each other by addition of an a, b, or c, etc. Consequently, all stitches that intertwine with two loops on each side are called Type 2 and so on. Within this system, there is no recognisable logic to the added letters. This makes her classification hardly workable.

The most recent notation system, and the one mostly used nowadays, is Hansen's notation as published in NESAT III in 1990. Hansen's system describes the path of the needle over and under the yarn of the previous loops, with a slash / indicating the change of direction after passing the innermost loop. Joins of different rows are described independently from this. Egon Hansen was well aware that this system was not complete, since in his article he asked anyone who could suggest alterations to his notation system to contact him. Sadly, he died shortly after the article was written and thus could not develop it further.

Hansen's notation is very well suited for describing basic stitches where the yarn passes the loops first in one direction, turns and goes back without another change of direction. Problems arise in the more complex stitches, such as when stitch loops are not used in sequence, or when directions change not just once, but more often. To describe these complex stitches he adds more symbols, like brackets () to indicate loops that are used more than once and colons : to indicate further changes of direction within a stitch. When loops are pushed out of alignment, the path of the needle is not tracked completely in this notation system, leading to additional confusion. In addition, as with Margrethe Hald's notation, Hansen's system excludes stitches that do not interlink within a row.

After Hansen's death, his notation has been used both in academic circles and by practitioners. Individuals have changed and added to it. For example, Sanne-Mari Pihlajapiha adapted the notation to include stitch patterns that split the last loop (Pihlajapiha 2010–2016c online) and Krista Vajanto added the words Down and Up to explain how to do the Finnish Turnstitch (Vajanto 2006 online).

There is, however, still a need for a notation system which covers all possibilities of nålbinding stitch patterns, in a systematic and logical way, including both the most simple stitches omitted by Hald's system and the most complex stitch patterns with asymmetrical loops, complex joins, out-of-sequence use of loops and multiple directional changes of the working needle.

The following notation system has been published by the author (Piening 2012) and was presented during the Forum of 2012. It is based mainly on Egon Hansen's and Margarete Hald's work. However, new elements and notation methods are introduced to allow the system to cover all stitch patterns and interlinking possibilities without having to resort to naming or additional descriptive texts. The system describes the path of the needle through the nålbinding fabric, similar to how Hansen approached the problem.

Piening's Practical Nålbinding Notation

Regular stitches

When a stitch is linked with a previous loop, the needle can pass that loop either by going over or by going under it. After the innermost loop is passed in that manner, the needle must turn back along the opposite side to make the necessary link. To finish the stitch, the needle also needs to pass the working thread, either by going over it or going under it.

This basic system of nålbinding stitches makes it logical to base a notation on these crossings as they are visible from the makers' side of the fabric. This is what the Hansen notation is based upon (Hansen 1990).

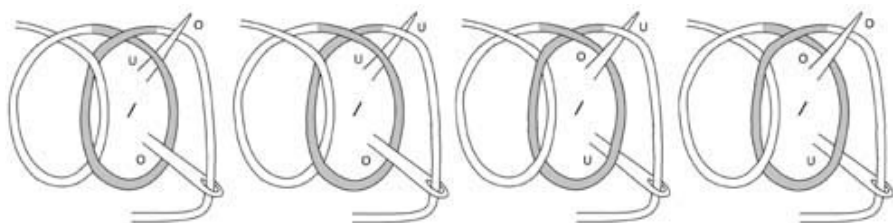


Fig. 2.1. Four different variations of linking with only one loop, showing the passage of the needle and the U or O crossings

The capital letters U and O are used to describe the crossings of every loop within a stitch. The four stitches in [Figure 2.1](#) show the passage of the needle and the U or O crossings. For nålbinding stitches with multiple loops, notating each crossing with an U or an O can quickly become unclear. The addition of a loop number solves this problem. The loop numbers are added to the letter defining the crossing, with the highest number indicating the innermost loop and zero indicating the needle passing the working thread. In stitches that

use the loops out of sequence, the loop numbers describe this process accurately.

Loop numbers can be added either as superscript (U^1), which is the author's preferred version, or by a regular number directly after the U or O ($O2$). To shorten long stitch descriptions with multiple loops that are crossed in the same manner, the notation indicates the first and last loop number in that crossing: 2,3 for two loops, 2–4 for more loops. For example, Hald describes a stitch used for a mitten found in Långaryd (Hald 1980, 298) made by going under the first and over the next four loops. The notation for that stitch is thus: $U^1O^{2-5}/U^{5-2}O^{1,0}$.

This results in a notation of the stitches in [Figure 12](#). as follows, from left to right:

O^1/U^1O^0 , O^1/U^1U^0 , U^1/O^1U^0 , U^1/O^1O^0
or, shortened: O^1/U^1O^0 , $O^1/U^{1,0}$, U^1/O^1U^0 , $U^1/O^{1,0}$

The slash in this stitch notation signifies a change of direction of the needle. When stitches are interlinked, the needle has to change direction within the stitch at least once, as it passes the innermost loop. This change of direction is already made clear by the loop numbering, as the highest number indicates both the number of loops used in a stitch and the innermost loop. For better clarity, however, an additional slash is inserted to mark the change of direction and the passing of the innermost loop.

It is technically possible to pass only this one loop on the opposite side (O, then U or vice versa) and all the other loops on the same side. However, in most of the documented historical stitches, the needle usually passes the loops on the opposite side from the way in on the way back, so $U1$ will become $O1$ and vice versa.

In some of the more complicated stitches, there is more than one change of direction. This is signalled by the use of a backslash \ which is followed by another slash / to indicate the next turn back towards the working yarn.

The stitch shown in [Figure 2.2](#) is an example of such a stitch with several direction changes. The first two loops are passed under, the third and fourth loop passed over, followed by a direction change of the needle. Instead of working all the way back towards the working thread, however, the needle passes only three loops (numbers 4–2), then turns inward again to go over loops 2–4 before turning outwards and finishing the stitch. The notation for this stitch, therefore, is as follows:

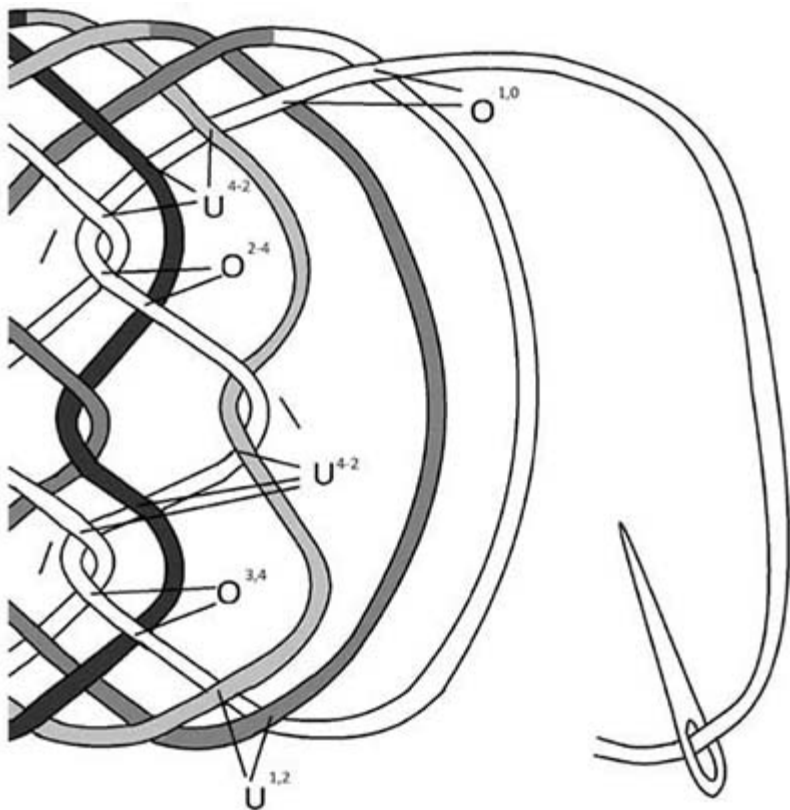


Fig. 2.2. Stitch found in socks from Oman, often referred to as Omani stitch (Collingwood 1987)

U¹U²O³O⁴/U⁴U³U²\O²O³O⁴/U⁴U³U²O¹O⁰, shortened to: U^{1,2}O^{3,4}/U⁴⁻²\O²⁻⁴/U⁴⁻²O^{1,0}.

Several changes of direction also appear when loops are worked out of sequence. An example for this is the stitch pattern in the mitten find from Åsle (Hald 1980; Hansen 1990), radiocarbon dated to around 1600 (Claffßen-Büttner 2012). The stitch is a three loop stitch worked around the thumb where the third loop is worked before the second.

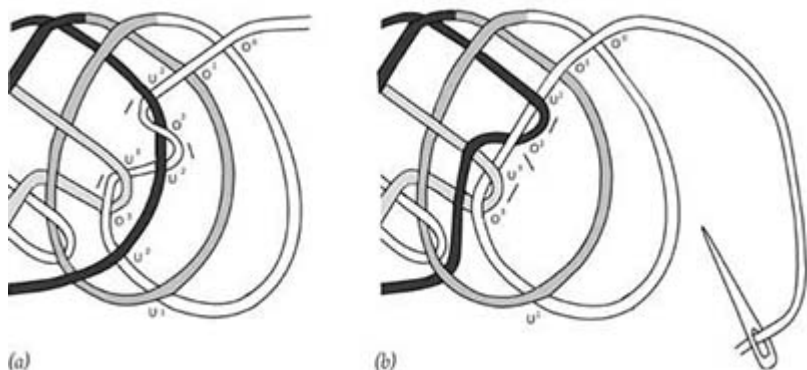


Fig. 2.3. Stitch with changes in direction

Figure 2.3a shows this stitch with the second loop (darkest shading) drawn in its original position and with the working thread (white) doing all the turning and twisting. This also shows the three changes of direction within this stitch. Figure 2.3b shows the stitch as it presents itself with the loops pulled into a different alignment by the working thread.

The first passing under of the second loop can be neglected since that part of the loop is pushed behind the third loop. The notation for this stitch is $U^1O^3/U^3\backslash O^2/ U^2O^1O^0$, shortened to $U^1O^3/U^3\backslash O^2/U^2O^1,0$. The loop numbers show the working sequence of the loops, made even clearer by the slashes and backslashes that signal changes of working direction.

Twisted loops

Most of the stitches described up to this point create a fabric in which the place where the innermost loop is passed can be visible, since a hole is inevitable by the pulling of the loops against each other.

By manipulating the loops in a different sequence or by twisting one of them, these holes can be avoided and a thicker fabric is created. Figure 2.4 shows this with $U^1O^{2,3}/U^{3,2}O^{1,0}$ (documented in the find from Mammen (Hald 1980)) on top and the same stitch, but with a twist in the third loop, below. The difference is clearly visible: twisting the loop closes up the holes in the fabric.

To indicate twisted stitches, the @ symbol replaces the usual U or O for the stitch: The stitches are usually twisted in the same direction due to technical reasons while working the stitch, so no indication of twist direction is necessary. This results in the following notation for the stitch shown in Figure 2.5, where the innermost loop is twisted:

$U^1U^2O^3@^4/U^3O^2O^1O^0$, which can be shortened to $U^{1,2}O^3@^4U^3O^{2-0}$.

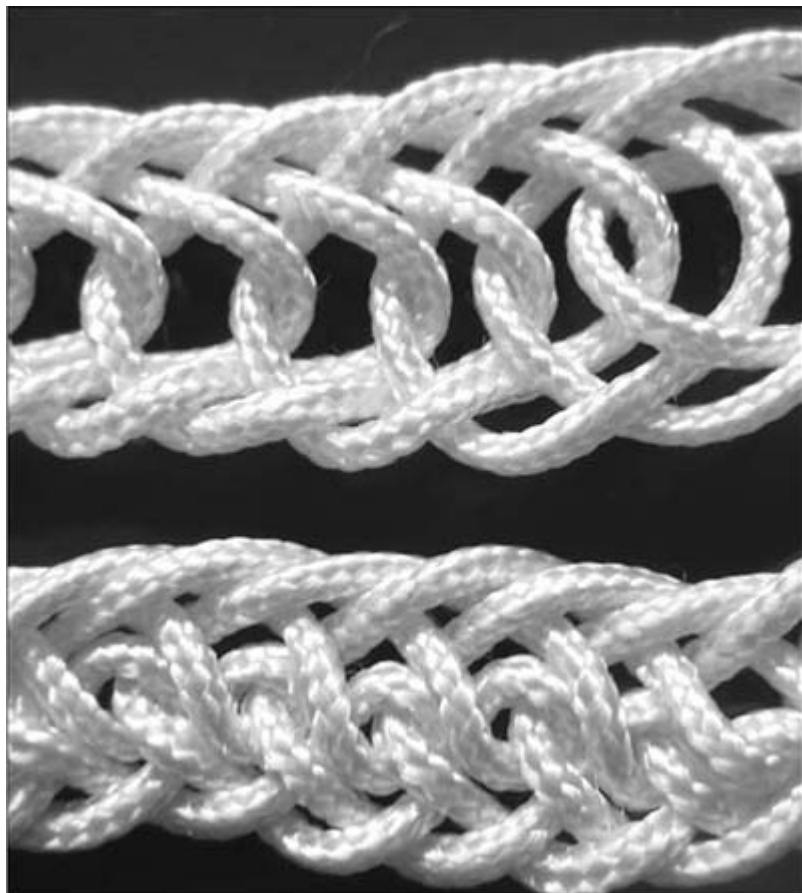


Fig. 2.4. Twisted loops (bottom) resulting in a thicker fabric with the same basic stitch (top)

The twisted loop is only noted once since the @ includes all the movements made with this loop at this stage. When the last loop is the one which is twisted, the slash is superfluous and can be omitted, since the direction change and the return path of the twisted loop are included in the movement of the twist.

In Finland other stitches are used in which a different loop than the last is twisted. Pihlajapiha describes a stitch in which the third loop out of five is twisted (Pihlajapiha 2010–2016f, online). This is also described by replacing the U or O with the @ symbol in the appropriate place:

$U^1U^2@^3O^4O^5/U^5U^4U^3O^2O^1O^0$, in short $U^{1,2}@^3O^{4,5}/U^{5-3}O^{2-0}$.

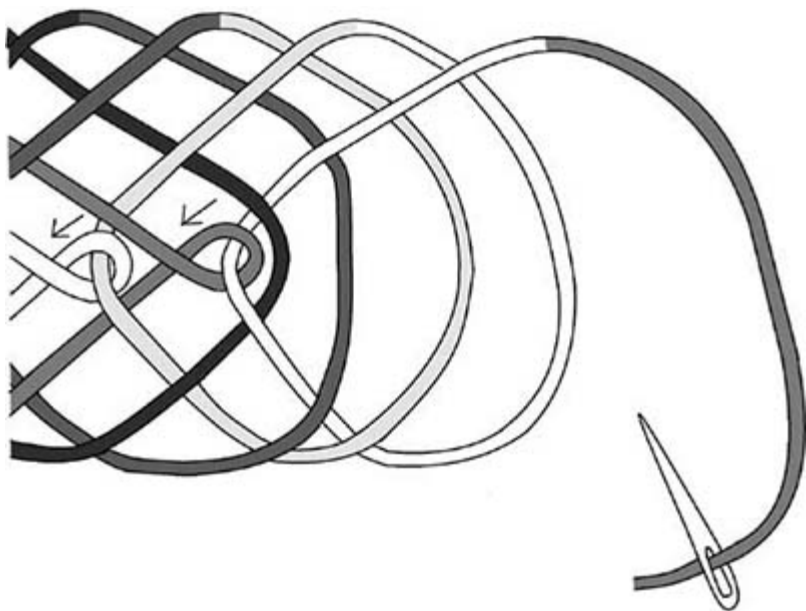


Fig. 2.5. Twisted stitch

The three loop version, with the second loop twisted, is shown in [Figure 2.6](#). The PPNN of this stitch is $U^1@^2O^3/U^3,^2O^1,^0$. In the second part of the stitch, the turned loop is passed Under. [Figure 2. 6](#) (left) shows the twisted loop drawn according to the sequence of loops when working. In reality, the loops in most stitches with a twisted loop will slide over each other, as indicated with arrows in [Figures 2.5](#) and [2.6](#) (left). This results in a tilted ridge on the back of the work, formed by the twisted stitches, as indicated in [Figure 2.6](#) (right). It also makes the working sequence of the stitches less obvious, which can complicate the analysis of these stitch patterns.

Ridges on the back of stitches can also be formed by using a different technique that is far easier to execute. For this, the loops used to create the ridge are not twisted, but only turned on their side so that the top part of the loops moves in front of the previous loops. A three loop version ($U^{1,2}/O^2\backslash U^{2,3}/O^3U^2O^1,^0$) is shown in [Figure 2.7](#); other variations use five loops. Both three loop and five loop versions form two sets of loops, separated by the turned loop. This variation can be described with slashes and backslashes:

$$U^{1-3}/O^3\backslash U^{3-5}/O^{5,4}U^3O^{2-0}.$$

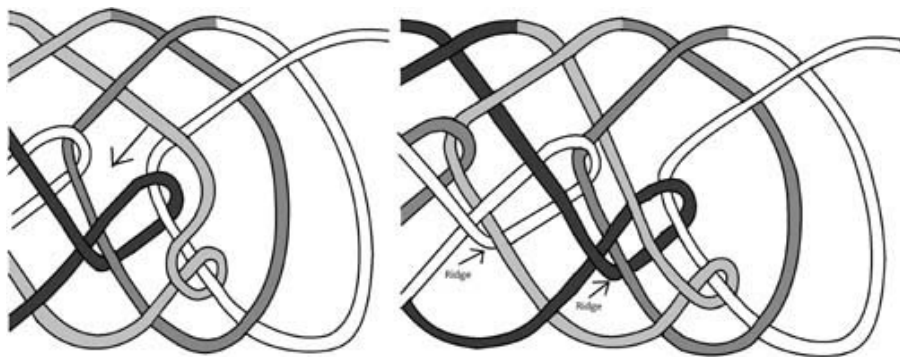


Fig. 2.6 Twisted stitches forming a tilted ridge

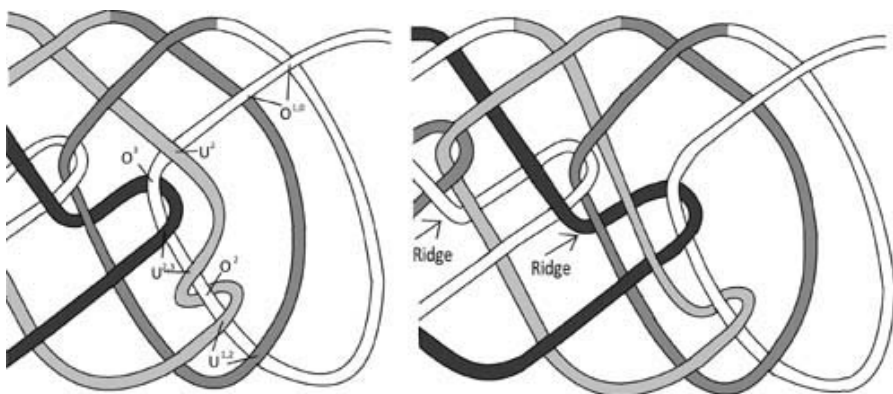


Fig. 2.7. Loops turned on their side instead of twisting

As there is no real twisting of any loop, the @ symbol should not be used. Shown in [Figure 2.7](#) is a three loop version; the left side shows the working thread twisting around the previous loops, the right side shows the actual alignment of the loops.

During the last few years nálbinders have been experimenting with the different possibilities to create stitches. This led to the invention of more complex stitches in which elements of historic stitches are combined.

Petra Ommen (2008, online) created two stitches in which the second loop is used twice, once before the third loop and once afterwards respectively, with an added turn (Philajapiha Double Curl stitch and Philajapiha Cross-Dalby Stitch). As [Figure 2.8](#) (Cross-Dalby Stitch) shows, this extra turn makes it difficult to distinguish between the different elements showing as the third loop.

The PPNN notation of this stitch is $U^1O^2@^3U^2\backslash O^2/U^2O^1,0$. However, this does not clarify whether the second loop is passed above, below,

or within the loop formed by the third loop around the working thread.

Adding a letter to the superscript number can solve this problem. The added letter 'b' indicates the loop closest to the join with the previous row; for three loops, 'm' indicates the loop in the middle—often formed by the next loop around the working thread—and 't' the loop that is closer to the ending of the stitch.

Since a capital B can be difficult to distinguish from the number 8, lower case letters are preferable in this situation. For the Cross-Dalby stitch, this clarified notation is:

$U^1O^{2b}@^{3t}U^{2t}\backslash O^2/U^2O^1,0.$

Joins between rows

In nålbinding, rows are not automatically connected as they are in knitting. Instead, each row or round must be intentionally joined to the previous row or round. This can be done in a variety of ways, depending on the complexity of the used stitch pattern and the planned use of the resulting fabric.

The different parameters for joining are the number of loops taken up into the join, the direction of the needle (from front or back of the fabric), and whether the top, the bottom or the middle of the previous row is joined to the current one. It is also possible to join combinations of top, bottom or middle of the previous row to the current one. This has to be noted together with the stitch pattern itself.

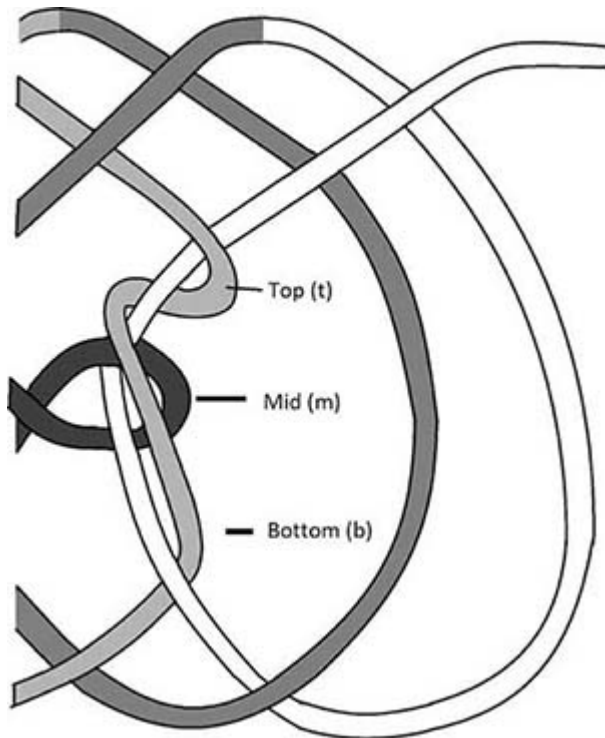


Fig. 2.8. Second loop used twice in one stitch

While it is technically possible to work a join in the middle of a stitch, joins in historical examples of náלבínding are worked between stitches. The loop or loops from the previous row are picked up when starting on the next stitch, so most modern nálbínders put the join description in front of the notation (Schmitt 2000).

The letters F and B are used to describe how the loop or loops of the previous row are picked up: either from the front or from the back. A number is added to describe the number of loops used from the previous row, usually only one or two loops are used.

Joining a row to the top of the previously worked row is the most frequent type of join, and no additional modifier is added. For joins made with the previous row at the turning point within a stitch, an M for Mid-is added. The stitch rows in the Ásle mittens are joined by picking up a loop from the bottom edge of the previous row, combined with one loop from the top. This has been described as F1 + 1 (Hansen 1990), but using Bottom 1 + F1 as introduced by Larry Schmitt is preferable (Schmitt 2000). To avoid confusion, graphs with arrows are used to indicate how rows are joined in more complex stitch patterns such as shown in [Figure 2.9](#) (top right).

The choice of join has a significant influence on the finished fabric.

Depending on how the loops at the beginning and the end of a stitch are worked, a join can create a number of effects ranging from a ridge to an almost lace-like structure. Joins worked in the edge of the previous stitches will result in a flatter join, with the rows lying next to each other. With the Bottom 1 + F1 join as used in the mitten find from Åsle, rows overlap partly, like tiles on a roof, and thus a thicker fabric is created, with less of the used stitch visible and a very distinct difference between front and back of the fabric. When the joins are worked in the middle (MFB or MBF), the top of the previous row will have the tendency to curl away from the fabric and this will show a ridge of horizontal lying knit-like Vs.

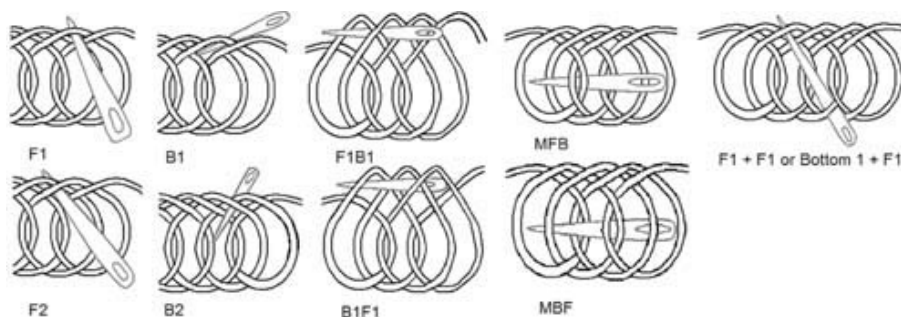


Fig. 2.9. Different joins possible. F: Front; B: Back, M: Mid-

For the simplest nålbinding stitches, often referred to as blanket stitch or single looping (Decker 2000b) the join is actually what creates the fabric, as an unjoined row would not be stable. This stitch pattern is not made by sideways linking with previous loops, but by going only over the working thread. The PPNN for this is O^0 . With this

O^0 stitch only three joins are possible; F1, F2 or F1B1. When making a similar stitch going under the working thread (U^0), it is necessary to join from the back to create a row of stitches.

Some of the oldest examples of nålbinding found yet, the 3000-year old Tarim Basin finds from the most western province of China contain amongst them a beret shaped hat, worked in a pattern of ribbed quadrants (Barber 2000; Mallory and Mair 2000). The stitch pattern used in this hat is O^0 with an F1 join within the quadrants, but the beret also shows that special effects can be created by combining different joins (Fig. 2.10).

In the quadrant borders of this beret and in another dome shaped hat from the Tarim Basin, but also in Egyptian socks from the Coptic period (Victoria and Albert Museum no. 2085&A-1900), a different join is used. Not the top loop is picked up, but the crossing of two top

loops, F1B1 (Fig. 2.9 top row, middle). This stitch pattern with this join creates the same structure as is seen in knitted fabrics with twisted stitches, but turned upside down. Western twisted knit stitches, often referred to as ‘knitting through the back loop’ corresponds to U^0 , while ‘Eastern European style knitting’ corresponds to O^0 . Both versions of this stitch pattern will create nearly the same effect, only the legs of the stitches will cross the other way around, just like in the two variations of crossed knitting. In Figure 2.11, A shows the legs of a stitch in Western ‘knitting through the back loop’ or nålbinding U^0 , B shows the legs of a stitch knitted in Eastern European style or nålbinding O^0 .

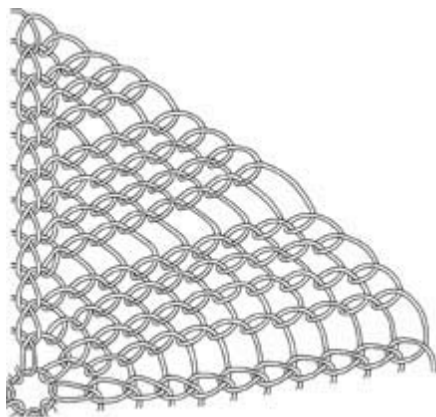


Fig. 2.10. Ribbed quadrant of the pattern from the Tarim Beret

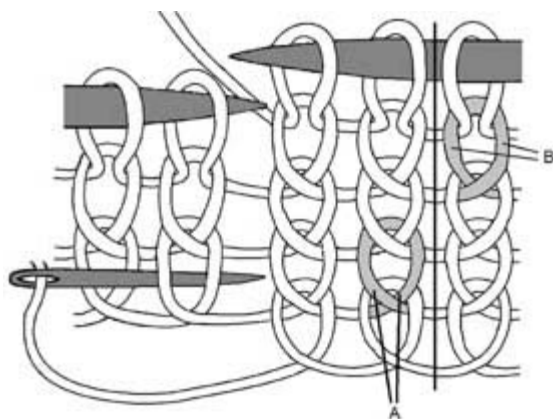


Fig. 2.11. Western twisted knitting (‘through the back loop’) on the left and eastern European twisted knitting on the right

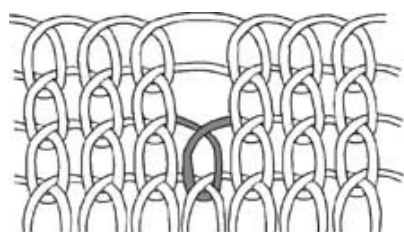
By working the join from back to front (B1F1), the knit-like fabric will look like purl stitches with a twist. In the past and even now

amongst scientists not well acquainted with nålbinding, this has led to falsely identifying finds with this stitch pattern as early knitting; for instance Xiaoyu Xin, 2015 states that the Tarim beret is knitting.

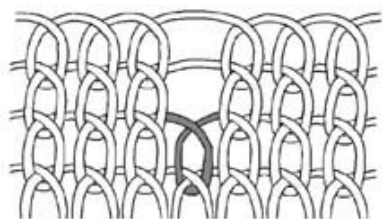
To distinguish between both techniques, detailed observations are necessary. Since nålbinding and knitting are done in opposite directions, knitting increases correspond with nålbinding decreases and vice versa (Fig 2.12). In knitting there are at least six different methods to increase. Of these, only two would be probable to be found as decreases in nålbinding. Knit increases in which a new stitch is made out of a twisted loop between two stitches correspond with an often used decrease in nålbinding, done by skipping one loop, when joining rows. Other knit increases made within a stitch can be done in nålbinding, but are very complicated to execute and thus very improbable. (Fig. 2.13)

In nålbinding, decreases are possible in which a single thread is passed through one or both previous loops. (Fig. 2.14) This cannot be executed in knitting, since the basic structure of knitting requires loops passing through loops. The two standard decreases in knitting, knit two together and slip-slip-knit are very unlikely as increases in nålbinding. While it is possible to make a new stitch around the same loops as used in the previous stitch, which would correspond with a knit two together, it is far more probable in nålbinding to make a new stitch by adding a blanket stitch between two stitches. This is both more fluid to work and causes no bump in the fabric (see Fig. 2.15). To avoid holes, an increase can also be made by making a blanket stitch going one row lower. Both these increases are impossible in knitting and thus a clear indication of nålbinding.

In addition to telltale increases and decreases, mistakes within the fabric structure can give an indication whether a structure is knitted or made with nålbinding.



Standard decrease in Coptic stitch F1B1 O°. Corresponds to a right leaning increase in knitting.



Standard decrease in Coptic stitch F1B1 U°. Corresponds to a left leaning increase in knitting.

Fig. 2.12. Knit and nålbinding decreases

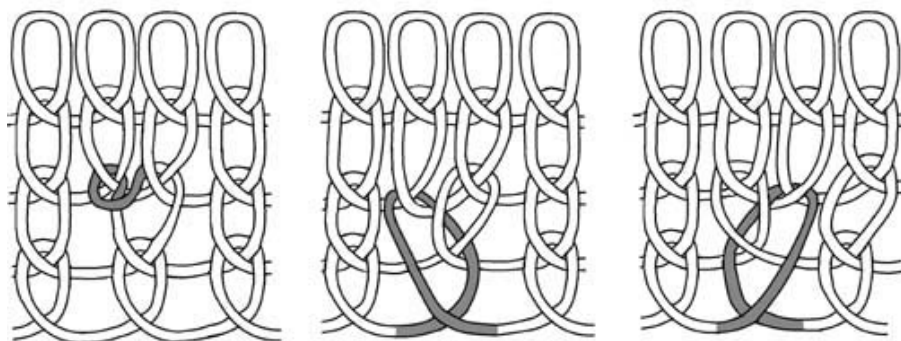


Fig. 2.13. Knit increases, from left to right: knit front and back of one stitch, left leaning lifted increase, right leaning lifted increase

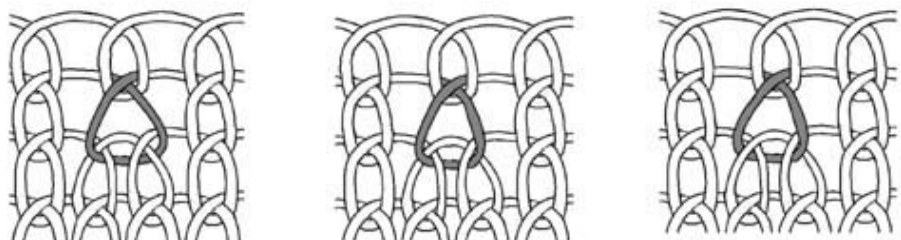


Fig. 2.14. Nålbinding decreases impossible as increases in knitting

Nålbinding cannot be made without crossed stitches, so without these crossings of the legs in stitches the fabric must have been knitted, either on needles or on a knitting dolly. If one or more stitches are not twisted in a fabric with twisted stitches, knitting must be the technique used. When stitches are crossed in the opposite direction, nålbinding is the more probable; to make this mistake in knitting, the stitch would have to be mounted differently on the needle and the movement to make the new stitch would have to be changed. In nålbinding, it would only have been the matter of passing the needle over instead of under the working thread or vice versa.

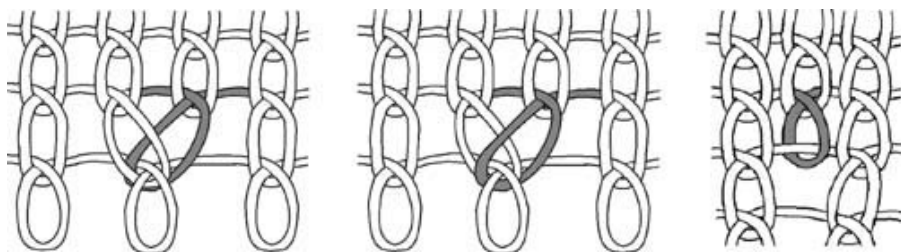


Fig. 2.15. From left to right: Slip, slip, knit decrease; knit two together; standard nålbinding increase

Notes on practical aspects

Just like with all textile or craft techniques, some procedures are easier to execute, while others are rather awkward or inefficient to perform. For nålbinding, this means that some variations are technically possible, but only rarely found. For instance, it is possible to twist the middle loop of the stitch shown in [Figure 2.6](#), $U^1 @ ^2 O^3 / U^{3,2} O^{1,0}$. However, this twisted stitch is very uncomfortable to work after the initial row. Either the loop needs to be twisted manually with the fingers of the hand that holds the work, or the join has to be made separately since the movement of the twist is completely the opposite to the other movements the needle has to make in creating this stitch.

More subtle patterning due to work efficiency or work style is the sequence of under or over in stitches. Historically, most stitch patterns start by going under one or more loops and end by passing over these same loops. This might be due to the practice of ‘working around the thumb’, a technique that is still in use in the eastern parts of Finland, where nålbinding has survived until the present day (Pihlajapiha 2010–2016d online). Whilst making stitches, the working yarn will have the tendency to wrap itself around the holding thumb when it is pulled through. Leaving the loop around the thumb makes creating stitches easier, and the thumb also serves as a stitch gauge. Loops often will need to be that large, especially if many loops are used or if a stitch is rather complex.

With loops placed on the thumb, they are already divided in the ones that are first worked under; on the thumb, and the ones that are first worked over; behind the thumb ([Fig. 2.16](#)). In working around the thumb, the front of the work lies folded around the thumb and the side visible is the back of the work. That means that to pass a loop by going underneath, one in fact does not have to do anything! To pass a loop by going over it, the needle must be passed between this loop and the thumb.

Conclusion

Nålbinding is a technique with a huge number of possible variations and hence not easy to describe. Variations in how the thread passes the loops can influence the stability of the stitch and whether the fabric will twist or lie flat. Variations in how the rows or rounds are joined also have a large impact on the overall structure, look and feel of the fabric.

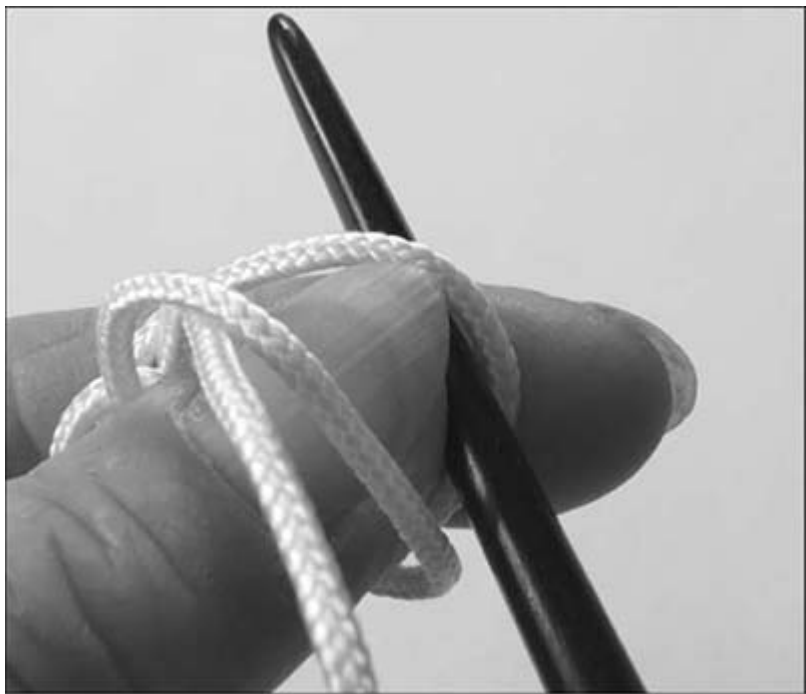


Fig. 2.16. Working around the thumb; one loop is on and one loop is behind the thumb

A good, concise notation system is thus a great help for accurately describing nålbinding stitches and nålbinding textiles. Based on the already widely known systems of Hald and Hansen, but altering and improving them where necessary, Piening's Practical Nålbinding Notation does offer a system suitable for describing stitches in accuracy and detail, which is useful both for the description of historical textiles and for the practical working of nålbinding.

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Chapter 3

Lost weaving tablets: Identifying weaving tablets during excavation

Heather Hopkins

The site of development for the Itchen Park and Ride, outside Winchester, Hampshire UK, was excavated during 2010. During this excavation, a collection of bone items was discovered in association. The majority were identified as being related to textile manufacture but one was identified as a gaming piece, although this identification was questionable. By chance, during packaging before museum deposition, the gaming piece was observed by a research archaeologist with a working knowledge of textiles who identified it immediately as a weaving tablet. This led to questions of how many tablets had been discovered during excavation and identified, how many had decayed or been discarded, and how many remained unidentified or mis-recorded in museum storage or other deposition sites, and how it may be possible to avoid this issue.

Tablet weaving is unlike weaving undertaken to make a broader cloth due to the method and structure. Both require the weaving of a weft through warps. In 'normal' loom weaving the warp is held taut through weight (e.g. warp-weighted loom) or through tension between beams (e.g. a 2-beam loom). When using a loom with secured warps, it is unusual to create an entirely warp-faced fabric, but it is possible to create a fabric that is warp-faced or that is warp faced on one side while being weft faced on the other. In tablet weaving, the warp is held taut either through tension between two beams or through tension applied by the weaver. In loom weaving the shed (gap) between the warps through which the weft passes is created by lifting selected warps – after the weft has passed through the warps a new shed is created and the weft secured by lifting different warps. In tablet weaving a shed is created through the distance between warps

on a tablet. Once the weft has passed through this shed a new shed is created, and the weft secured, by turning some or all of the tablets. This has the effect of twisting the warps together, which is not possible on a loom. This also has the effect that the fabric becomes ‘warp-faced’, the warp is visible and the weft usually is not. Through this twist is it possible to determine whether the fabric was tablet woven or woven on a loom. The method of tablet weaving is described in greater detail by Goslee (2013). Examples of tablet woven artifacts include Eric of Pomerania’s belt (Holmquist 2013).

Reliability of historic discoveries of weaving tablets

The earliest finds of ‘weaving tablets’ do not actually mention weaving tablets. Instead, they record the discovery of textile that has been tablet woven. This does make sense - weaving tablets are thin and fragile, so it is understandable that few have survived and that the presence of tablets may sometimes only be discerned from the existence of tablet woven fabrics. But this approach was and remains controversial – it requires application of reverse engineering from a modern assumption. Unless the textile shows the twisting together of the warps or otherwise had sufficient mistakes or intricacies within it that highlighted moves that could only have been made using tablet weaving, it is possible that the textile was made using another method and that the ‘finding’ of tablet weaving is a hopeful modern assumption. It is possible that it is the wish to find weaving tablets is what causes the finding of weaving tablets, particularly as years later these ‘finds’ can be re-classified as ‘votive offerings’ (after Collingwood 1982) or are technologically questionable, e.g. have no holes for the thread – see below (after Barber 1991).

An example of this was the decades-long debate between scholars at the beginning of the 20th century arguing where tablet weaving had begun. Lehmann-Filhes argued that it began in Mesopotamia (1901, cited by Barber 1991 as 1908) while van Gennep and Jéquier (1916) believed that tablet weaving began in Ancient Egypt (Barber 1991). Both cited the patterns discovered in apparently non-tablet woven textiles and monuments as evidence, as no actual tablets or tablet woven fabrics had been discovered (Barber 1991, 118). Barber cites woven borders depicted on Minoan paintings as evidence of tablet weaving (Barber 1991). There were 40 square ivory ‘tablets’ found in Mesopotamia, cited as evidence for tablet weaving (de Mecquenem 1905, cited by Barber 1991 as Mecquenem) but these were small (1.5–

3.5cm) and most did not have the holes required (Barber 1991, 119). Van Reesema (1926, 26–50) showed that when attempts were made to re-create textiles through tablet weaving that would mimic the evidence used by van Gennep and Jéquier (from pattern in monuments and textiles) to show that tablet weaving had existed this early, van Gennep and Jéquier's conclusions were shown to be inaccurate (Barber 1991, 120) and that the Egyptian motifs could be more accurately worked in double sprang (Collingwood 1974; 1982).

After mathematical analysis of Ramses III's girdle, according to Barber (1991, 120–1), Otfried Staudigel concluded that it could only be tablet woven. Barber goes on to note that such a sophisticated artefact indicates access at this time to an already existing lengthy tablet-weaving tradition (1991, 120–1). Staudigel's mother wove a replica to demonstrate the validity of Staudigel's conclusion. But both have since been found to be incorrect as the woven threads in the original do not twist around each other (Staudigel 1960–61, 1975, cited in Collingwood 1982). Likewise Crowfoot and Roth (1923) showed that 'Egyptian tablet weaving' could have been made through ordinary weaving, especially as it did not have twists in it that would have resulted from tablet weaving (Barber 1991, 120). Barber believes that tablet weaving originated in the Causcausus in 3rd millenium BC and eventually spreading into Europe during 1st millenium BC (Barber 1991). Hansen believes from the available evidence that the earliest tablets date from 3rd–4th century in Spain and that tablet weaving began around the Mediterranean during 'the first half of the last century B.C.', spreading to northern Europe in the last half of the first century BC in conjunction with upright looms, then peaked during 'the Roman Iron Age' with a simultaneous peak in upright looms (Hansen 1990, 61–62). Barber cites that most finds are Viking (Barber 1991, 119).

Hansen relates that for part of Hald's re-discovery of tablet weaving during 1930s–1950s, Hald combined Lehmann-Filhes work on Nordic material with ethnographic material, 'whereby several interpretations arose that have haunted the archaeological descriptions until recent years'. Hansen has re-interpreted the work, including reinterpreting findings that Hansen sees as misinterpretations by Hald (Hansen 1990, 9, 64). This is an example of why, although inclusion of ethnographic evidence showing an unchanged technique continuing in its original locality and resources is important, there needs to be an allowance for 'drift', that a technique may have changed over time and its modern inclusion for interpretation of artefacts may be misleading.

The sparsity of finds has led to some speculation about how archaeological weaving tablets were developed. Hansen says that Hald's theory that weaving tablets began with two holes, then adapted to four, 'must be rejected' as weaving began with tablets with four holes (Hansen 1990, 61). Hansen also says that tablets began and continued in the same form, although the size varied. He believes that tablets were often made of wood, irregular and possibly with a thickness that prevented simultaneous turning of single tablets (tablets not adjacent to each other) – leading him to conclude that they were turned in packs (tablets adjacent to each other turned in groups) which could lead to mistakes that can be seen in the fabric (Hansen 1990). The explanation that the cards must have been turned in packs is concerning, insofar as it appears to be a hopeful explanation of a flaw that was discovered after a new technology was 'reverse engineered' on to an older problem.

A further issue of applying a new technology on to an older technique follows Hansen's citation that when tablet weaving was re-discovered in the modern era, playing cards were used before any wooden tablets had been discovered (1990). Assuming the use of rectangular playing cards, a question left unanswered is why playing cards were chosen, rather than, for example, making plain square or multifaceted tablets from another available but stronger material (the author used discarded cardboard as a sturdier material that was readily replaceable and could be cut to size and shape as desired). Use of modern playing cards leads to further questions, such as if convincing tablets had not yet been discovered, how were playing cards realised to be suitable at all? Applying a new artefact to an older problem can be misleading: the new artefact will have entities relating to its modern use and this can be assumed to be relevant to the older problem it is applied to. Playing cards are numbered – which in tablet weaving may be misleading – the number may not be seen during use, but could be perceived as significant by someone unaware of this. How use of a modern artefact is reported can also influence the understanding of the technique in years to come: saying that playing cards are used does not say if they were used in their original rectangular shape or cut to a specific shape – an assumption that a reader would know they were cut to square assumes a logic leap on the part of the reader that in years to come may be in a different direction.

The assumption that certain technology did or did not exist, when it may be that the evidence to demonstrate the situation just has not yet been discovered, may cause misleading technologies to be applied to

fill the gap. For example, Barber (1991, 121-122) cites that a bronze pin from Nalchik in the Caucasus shows an impression of tablet weaving which shows that it dates to the 3rd millienium BC, citing that the impression could not be made by spool knitting, a reasonable alternative as no find had been made this early. This does not allow for future findings that may show alternative technologies did exist this early, such as the finding of spool knitting in the Roman fort of Maximinianon (1st/2nd century AD) in the Eastern Desert of Egypt showing its existence much earlier than originally believed (Cardon 2003, 646).

When authors write about manufacturing equipment that has been found in archaeological excavations, it is not possible at face value to know whether the author is citing uses of the equipment from any practical knowledge or if they are superimposing their own or others' theoretical ideas. An example of this – the argument during the early 20th century – is shown above. Additionally, when Walton Rogers states that ‘Most tablets are at least 30mm square’ (citing Roes 1963, 149–150; Wild 1970, 140–141; MacGregor 1985, 186, 191; Pritchard 1994) and that smaller weaving tablets are used for delicate work (Walton Rogers 1997), it is not known if this is an assumption. Weight difference does not make a difference to thickness of spun thread (Kania 2013) and likewise tablet size does not automatically make a difference to delicateness of work.

Through literature review, the earliest undebated find of tablet weaving comes from Hallstatt in Austria, with finds dating to 6th century BC. In each instance the evidence comes from woven finds, not the discovery of weaving tablets ([Table 3.1](#)).

<i>What is it?</i>	<i>Citing</i>	<i>Published in</i>
Textile found at 6th century tomb at Hohmichele, Hallstatt, needed 14 cards.	Hundt 1962, 208	Barber 1991, 119
Textile found at Hallstatt, needed 7 cards	Hundt 1960, 67	Barber 1991, 119
Textile found at Apremont, Eastern France, Hallstatt chieftain, 35 tablets needed.	Hundt 1970, 67	Barber 1991, 119
Thorsbjerg cloak/	Schlabow 1976, 64	Cited in Barber 1991,

mantle, interwoven
border of 170 or 178
tablet to weave the
four edge borders.

Table 3.1. Earliest finds demonstrating tablet weaving – each is woven fabric

Collating data: Comparing citation of weaving tablets

Numerous authors have cited the discovery or existence of weaving tablets. Some, such as Peter Collingwood (1982) and E. J. W. Barber (1991), have published a catalogue list ([Appx 3.1](#)). The relatively early publication date of some lists, such as Henshall (1950), may be problematic: the list informs that the tablets existed, information that would otherwise be lost but, due to the passage of time, it is unlikely if the location of deposition of the tablet is still accurate. Older lists may also refer to inaccessible or lost references. A further issue of citation is demonstrated by Hansen (1990) who refers to Hald's 'works from the period 1930–50' in the text, without citing them, then only includes Hald (1980) in the referenced 'Literature'. This means that it is not possible to ascertain the works referred to. A fuller list of Hald's works of this period are given in the bibliography below to assist enquiry.

Newer lists have the opposite problem –too much contemporary data rather than too little –and unless photos are published with newer lists it is not possible to tell absolutely whether the tablet referred to is the same as that referred to by another author. There appear to be few published sources available and each one refers to the others, meaning that a working knowledge of each is advantageous in order to place the findings of any in context.

Collingwood (1982) cites Schuette (1956) as the fullest history available. This citation demonstrates a common problem with sources. If Collingwood (1982) cites a source from 30 years earlier, today that source is more than 60 years old. This can be a mixed blessing in today's internet age: older publications are more likely to be out of copyright and may be scanned online to prevent their being lost. Newer publications may still be in copyright or have a living author as custodian. The approach to sources has changed since the development of the internet: research completed 10 years ago was seen as unreliable if it relied heavily on sources from the internet,

whereas today the opposite may be true as internet sources may be attached to a reliable source, such as an accredited museum, and continually updated in a manner that printed publications cannot be.

The list of citations below seeks to highlight that duplication of reporting can occur, causing a single tablet to appear to have been discovered multiple times. The list is partial, as it only aims to include well-known, mainstream sources. Compiling this list of citations highlighted difficulties with working with sources from diverse periods and backgrounds. When publishing results there are different audiences to cater for, such as experimental archaeologists who may wish to replicate the item. To do this they must have sufficient data. Someone who does not understand how a tablet works may not realise the data they require and so leave it unpublished. Likewise, a report that looks incomplete years later may simply have gaps due to the unavailability of data, not from any willful or accidental neglect of the writer. To say how many pieces of evidence are missing in archaeology would take much longer than to say what has been found. But thankfully, there is still a wealth of archaeological finds and data, or to quote Collingwood (1982, 10): ‘A great deal of material survives from the past, much of which has not been subjected to technical analysis. It would take a lifetime to locate and examine it all in an effort to construct a continuous story of the craft’s development.’

An incidental issue is that of measurement. The earliest British publications record the finds in Imperial. Mainland Europe and later British finds record in metric. The size of the tablets may have been rounded up or down for ease of publication, misleading the comparison made between them decades later.

Creating a history of tablet weaving or a history of its re-discovery is not within the scope of this article. There are numerous publications that already do this (e.g. Hansen 1990; Barber 1991) and unnecessary repetition would cause confusion. But putting the weaving tablet find from Itchen in context with what has already been discovered requires a review of published catalogues of finds ([Appx 3.1](#)). On review it was found that some individual finds were repeated in the literature, suggesting duplicate reports of the same find. To clarify what had been found so far a consolidated list for the publications from Barber, Collingwood, Walton Rogers and Hansen was compiled ([Table 3.2](#)).

The finds from Itchen

The weaving tablet was found during an excavation undertaken at Itchen Farm, in preparation for development of the land to form

Winchester's Park and Ride. The site extended across 3.29 ha and lay to the south of Winchester, between Otterbourne Road, which is Roman in origin, and the modern M3 motorway. The wider landscape contains the remains of Roman settlements and a plethora of other archaeological sites. The remains of activity included ditches, trackways, enclosures, pits, postholes and human inhumations. All archaeology was cleaned and excavated by hand, with domestic and industrial deposits being fully excavated (Lewis and Preston 2012).

The site had six phases:

Phase 1: Early Neolithic

Phase 2: Bronze Age

Phase 3: Late Iron Age/Early Roman (A and B, both Flavian)

Phase 4: Early Roman

4A, Late 1st century, probably into early 2nd century

4B, Early to middle 2nd century

4C, Late 2nd–3rd century

Phase 5: Late Roman (4th century)

Phase 6: Post-medieval

The Roman phases of the site show evidence of enclosures that were defined, re-modelled and re-defined between the late Iron Age and late Roman periods. The site appears to have been abandoned in the middle of the 4th century. The latest features appear to show the dismantling and clearing of occupation. There are no structural remains and until the end of the period there are no pits for storage or refuse, although there are abundant finds in the ditches.

<i>Find</i>	<i>Object published in</i>	<i>Citing</i>
Beechwood tablets, square, 3 cm ² , 4 holes. found in Grave 200 of Cigarralej, East Spain. 400–375 BC. Accompanied by charred textile with tablet woven starting border. 33 tablets were needed to create the border (Hundt 1968, 189–193)	Barber 1991, 119	Hundt 1968, 189–193, fig 5. Collingwood 1982. Hansen 1990, 61: 'The earliest tablets preserved are from Cigarroleja in Spain and are 4th–3rd century B.C.' (Note: conflict with Hallstatt finds?)
Two square tablets from burial at Dejbjerg bog, Jutland,	Collingwood 1982; Hansen 1990; Barber 1991	Hald 1950; Petersen 1888

Denmark. 1–2 century
BC.

Wookey, Somerset, Henshall 1950; cited
Iron Age, Triangular, 2 in Collingwood 1982
inches, 2 found, 3
holes, Wells museum,
ref Arch. Lxii, 582.

Many Roman/ Collingwood 1982 Behrens 1925;
Northern European Henshall 1950; Wild
British tablets. 3–5 cm. 1970
1st–4th century AD.

Most bone, some
decorated, 1 bronze
(Legionary Museum
Caerleon). One
wooden (Friesland
Museum). Half are
triangular, may not be
tablets. Worn grooves
suggest were used
with thread/rope. 1
has central hole
(Friesland). 1 six
(Alchester).

Alchester, Henshall 1950; cited
Warwickshire, Roman, in Collingwood 1982
Square, 1½ inches, 2
found, 4 (6) holes,
now in Ashmolean.

(*Antiquaries Journal* ix
(1929), 134)

Richborough, Kent Henshall 1950; cited
Roman Square, 1 2/5 in Collingwood 1982
inches, 1 found, 4
holes, Richborough
museum (Bushe–Fox
1949, pl. lvi, 268)

Tain Ross-shire Henshall 1950; cited
Midden Square, 1 3/8, in Collingwood 1982
1 found, 4 holes, NMA
Edinburgh (HR 819)

(*Proceedings of the*

*Society of Antiquaries of
Scotland* lxx, 353, 10)
[Roman?]

Corbridge Roman Henshall 1950; cited
Triangular, 1 7/8 in Collingwood 1982
inches, 2 tablets, 3
holes, Corbridge, no
ref.

Keil Cave, Kintyre, Henshall 1950; cited
Roman-British, in Collingwood 1982
Triangular, 2 inches, 1
tablet, 3 holes,
Campbelltown
(*Glasgow Herald*, 28
Sept. 1935)

Richborough, Kent, Henshall 1950; cited
Roman, Triangular, 1 in Collingwood 1982
3/5 inches, 5 found, 3
holes, Richborough
(Bushe-Fox 1949, pl.
lvi, 267)

Silchester, Roman, Henshall 1950; cited
Triangular, 1½ inches, in Collingwood 1982
2 found, 3 holes,
Reading, no ref.

Woodcuts, Dorset, Henshall 1950; cited
Romano-British, in Collingwood 1982
Triangular, 1 7/8, 1
found, 3 holes,
Farnham museum
(Pitt-Rivers 1887, pl.
xviii, 6)

Wroxeter, Salop, Henshall 1950; cited
Roman, Triangular, 2 in Collingwood 1982
inches, 1 found, 3
holes, Wroxeter
(Bushe-Fox 1914, 16)

Deck of cards from Barber 1991, 119
Coptic Egypt
(Staudigel 1975, 77
pl.4)

25 tablets, 4 cm², Collingwood 1982 Reuleaux 1902;

wood in decorated
ivory box, Coptic
grave Antinoe, Egypt.
4–5th century AD.
Never used.

Tablets from Gayet Collingwood 1982
excavations. Similar
date to Antinoe? 4th–
5th century

Roughly square bronze Collingwood 1982
plate with round
corners and 4 holes.
6th century grave.
Oxfordshire. 2.5cm².
Pendant?

Bone tablet. Square. 4 Collingwood 1982
holed. 7th century
burial. Kingston, Kent.
Destroyed by fire.
Found with sewing
implements.

Faussett 1856.
Includes description
and drawing of a
square bone tablet.
Note similarity to type
and associated finds to
Itchen find.

‘Single, small, almost Walton Rogers 1997
square bone plate’. No
wear marks. Damaged
–discarded?

Coppergate, York
On Oseberg ship. 52 Collingwood 1982
tablets, 40 mm,
square, wood,
threaded up with linen
warp. Norway. AD
850–900. Wooden
cask also had 3 tablets.

Götze 1908, 488 fig. 5;
Hald 1950, 453;
Schuette 1956, 5;
Munksgaard 1974a, 43
fig. 22.

Barber 1991, 119
Walton Rogers 1997

Grieg 1928, 180–1
Grieg 1928; van
Scheltema 1929. Grieg
formed the main
source for information
about textile tools in
Oseberg ship burial,
the textiles having still

Bone tablet. 4 holes. Square. Birka, Sweden. Associated with find of tablet weaving. AD 900	Collingwood 1982 Hansen 1990 Barber 1991, 119	not been published. Geijer 1938 Götze 1908, 488 fig. 5; Hald 1950, 453; Schuette 1956, 5; Munksgaard 1974, 43 fig22 Geijer 1938 Geijer contains highly detailed and exhaustive account of these 9th-century textiles, including many tablet-woven bands. Many illustrations and references. Markova 1977; Stankova 1967.
2 tablets. Bone. Square. Four corner and one centre hole. Boneworker's workshop. Starom Meste, Czechoslovakia, 'Great Moravian Period' 9th century	Collingwood 1982	Stankova 1967 includes description of the two tablets found at Starom Meste.
Rectangular bronze tablets from Anduln, near Klaipeda, Lithuania 'USSR', 9th–10th century? 1.1–2.7 cm. Votive? Found with woven borders and sewing implements.	Collingwood 1982	Götze 1908
4 hole. Tablet. Lund, Sweden. Grave. AD 1200. Runic inscription suggests closer to AD 1000.	Collingwood 1982 Barber 1991, 119	Olsen 1908; Bqt 1943 Götze 1908, 488 fig. 5; Hald 1950, 453; Schuette 1956, 5; Munksgaard 1974, 43 fig22 Olsen 1908

attempted to elucidate the inscription on tablet found at Lund. Olsen 1908 attempted to elucidate the inscription on tablet found at Lund. van Reesema 1926, 14

Björkö, no details Barber 1991, 119
 Burrain, N. Ronaldsay, Henshall 1950; cited
 Broch site, circular, in Collingwood 1982
 1¼ inches diameter, 2
 found, 2 holes, NMA
 Edinbrugh (GB 236)
*((Proceedings of the
 Society of Antiquaries if
 Scotland x, 11)*
 Jarlshof, Shetland, Henshall 1950; cited
 Broch site, Circular, 1 in Collingwood 1982
 ¼ diameter, 2 found, 2
 holes NMA Edinburgh
 (GA411) museum, 2
 holes, NMA Edinburgh
 (GA 411)
 Unknown, Broch site Henshall 1950; cited
 (no location), circular, Collingwood 1982
 1¼ diameter, 1 found,
 2 holes, in Hunterian,
 Glasgow (B 1914, 491)

Table 3.2. Consolidated list of fi nds of weaving tablets, taken from wider literature

Pit 2735 stands out due to the quantity and variety of finds it contained. It contained a concentration of iron tools and two copper alloy bracelets which were small enough to fit a child. Metal fittings appear to have been part of a wooden box. The concentration of finds appears to show the clearance of a workshop before abandonment (Crabb 2012). Pit 2735 also contained animal bone, vitrified nails, metal items, glass, brick, 4.863 kg of tile, 25 sherds of 4th century pottery, two pieces of quern, two coins: Tetricus II (AD 271–273) and Magnentius or Decentius (AD 350–353). These are the latest items on the site. The pit also contained a small bone cylinder of unknown use and a weaving tablet (Hopkins 2012). The artefacts were deposited

The decline in activity on the site coinciding with the growth of Winchester during the Roman period means it is probable that the site's occupants relocated to Winchester at this time. The ditches of the 4th century coincide with those of the 1st century, suggesting that the earlier ditches were still visible and re-used. The major period of activity on the site was during the 4th century. Pits that appear to have been used as wells were dug, suggesting an increase in occupation. The large quantities of brick and tile suggest the presence of a building, although no remains of this have survived below ground level. Ninety-five kg of ceramic building material were discovered overall (Milbank 2012). The site was finally abandoned in the middle of the 4th century. Later intrusion, such as the Saxon burials and the post-medieval ditch were not a re-occupation of the earlier Roman site.

The weaving tablet

Five bone objects were discovered on the site: a carved pin (Fig. 3.1), a spindle whorl (Fig. 3.2), a comb (Fig. 3.3), a hollow tapered cylinder (Fig. 3.4) and a weaving tablet (Fig. 3.5). A second spindle whorl made from ceramic material (Fig. 3.6) and a single ceramic loom weight (Fig. 3.7) were also found. These are described in the site report (Lewis and Preston 2012).

The comb was not suitable for use as a weaving-beater due to its curving angles. Combs of this design are described as wool combs for fibre combing. Similar combs have been discovered in the neighbouring county of Wiltshire (Cunnington 1923 cited in Cunliffe 1974) and are on display as wool combs at National Museum Scotland (viewed by author 2018). However, their actual practical function is unclear.

The hollow cylinder and weaving tablet were discovered in the same pit, in contexts next to each other. The hollow cylinder tapers and weighs 5 g. It is 31 mm long, 15 mm diameter, made from bone 2–3 mm thick. Lateral rings are carved at the top, base and at thirds, dividing the cylinder into three. The rings stand proud –they were created by removing material around them. The ends were neatly cut. There is a smooth wear pattern and corrosion, possibly caused by the corrosion of associated metal, along the length of one side. This cylinder is of unknown use but a similar find was discovered at Coppergate (Walton Rogers 1997) and interpreted as a bone reel for sewing thread.

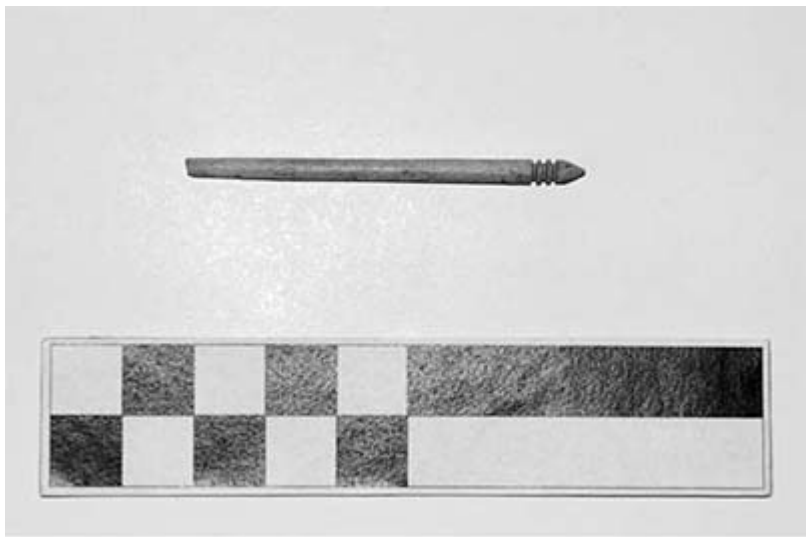


Fig. 3.1. Bone pin, 4th century



Fig. 3.2. Bone spindle whorl. 4th century AD



Fig. 3.3. Bone comb, probably used for combing wool. 4th century AD



Fig. 3.4. Bone, hollowed, tapered cylinder. Use unknown. 4th century AD



Fig. 3.5. Weaving tablet. Note damage indicating pulled yarn. 4th century AD



Fig. 3.6. Ceramic spindle whorl. 4th century AD



Fig. 3.7. Ceramic loom weight. 4th century AD

The weaving tablet is well-preserved – most of it remains and the wear caused by thread can be discerned on the four holes. It appears that it was square. The intact side is 37 mm long, the broken side is 27 mm. It weighs 2 g. The two intact holes have elongated from 4 mm diameter to 8 mm diameter. Additional grooves may be discerned running from the holes, perpendicular to the edge of the tablet. This suggests that the item is a weaving tablet and that it had been used. This was the only tablet found.

Faunal remains indicated management of livestock including sheep. Discovery of a loom weight and a weaving tablet suggest sophisticated textile manufacture was taking place at the site. During the 4th century, the age of the weaving tablet, most sheep/goat present at the site were slaughtered before 4 years of age, most at 1–2 years. This happens to be the age at which best quality lambswool is acquired, which may suggest a delay in slaughter to collect the wool. Delaying slaughter increases the quantities of wool produced and allows diversity of the types of wool produced, suggesting specialisation on the site.

How the weaving tablet was found

The site at Itchen was excavated and overseen by archaeologists with up to 30 years of excavation experience and who had been educated

up to and including PhD level. The weaving tablet had been cleaned, recorded and identified as ‘miscellaneous gaming piece’, although it was not possible to say which game it was from. As it was being processed before museum deposition, at Hampshire County Council’s archive in Winchester, one of the excavation unit’s researchers, who had an interest in textiles, happened to see it and immediately recognised it as a weaving tablet. It was duly relabelled.

This prompted the question of identification. When writing the finds report from the Itchen site, it emerged how few weaving tablets had been recorded. In 1950 Henshall listed only 12 sites from the British Isles (Henshall 1950). Thirty years later Collingwood cites only 11 further sites throughout Europe (Collingwood 1982). Furthermore, some of the ‘tablets’ were now doubtful, as it was probable that they were votive offerings or misinterpreted jewellery (Collingwood 1982). This prompted the question of how many other tablets have been found that had been mis-identified, not reported or not documented in a sufficiently mainstream way to allow researchers to become aware of their existence. With sufficient time and resources it may be possible to scour every museum in the world for these lost tablets, but as Collingwood notes above, it would take ‘a lifetime’ and it would not be possible to verify how complete the survey would be.

Towards the future

Finding this tablet opens up the possibility of a circular argument: it is possible that tablets have not been recorded or published as such simply because they have not been recognised or identified. If an excavation unit cannot identify the finds correctly, mislabels them and sends them for museum deposit, how many more weaving tablets are sat in storage waiting to be found?

This tablet shows the problems of ‘Dunning-Kruger’ reasoning, where someone knows so little about a subject that they do not know how little they know (Dunning-Kruger 1999). Someone who has never heard of weaving tablets is unlikely to recognise them, but also will not know that they cannot do so. This makes the case for well-read researchers in excavation units, something that may be seen as a luxury as commercial units operate as businesses where every part must ‘pay its way’. But what is possible with today’s technology is that any items that would otherwise be unidentified, or called a ‘miscellaneous gaming piece’ could be photographed and put online, allowing identification. This was still a fledging technology and idea in 2010, but as time progresses and the paradigm shifts, the

technological ability and mindset that allows this will develop. Encouragement is required!

Acknowledgements

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Appendix 3.1

Original lists of weaving tablets, by author citation

<i>Find</i>	<i>Cited by</i>
La Tène period (500 –1 BC): Deibjerg, Denmark (Hald 1950)	Barber 1991
<i>Cited by</i>	
Grave 200 of Cigarralejo needed 33 tablets for border (Hundt 1968 189–193)	Barber 1991, 119
La Tène period: Grave 200, Cigarralejo, East Spain, (Hundt 1968, 192–193, fig. 5)	Barber 1991
Items increase in La Tene period in number and complexity. Thorsberg Mantle would have needed 178 tablets to weave the four edge borders. (Schlabow 1976, 64)	Barber 1991, 119
at Lund, (Götze 1908, 488 fig. 5; Hald 1950, 453; Schuette 1956, 5; Munksgaard 1974a, 43 fig. 22)	Barber 1991, 119
Deck of cards from Coptic Egypt (Staudigel 1975, 77 pl.4)	Barber 1991, 119
Björkö (van Reesema 1926, 14) At Birka, (Götze 1908, 488 fig. 5, Hald 1950, 453; Schuette 1956, 5; Munksgaard 1974a, 43 fig. 22)	Barber 1991, 119
‘on the Oseberg ship, where they are even threaded up with a warp’ (Götze 1908, 488 fig. 5, Hald 1950, 453; Schuette 1956, 5; Munksgaard 1974a, 43 fig. 22)	Barber 1991, 119
Earliest is 6th century BC Hallstatt tomb at Hohmichele, needed 14 cards (Hundt 1962, 208); Hallstatt, needed 7 cards (Hundt 1960, 67)	Barber 1991, 119
Apremont, Eastern France, Hallstatt chieftain (Hundt 1970, 67, 35) tablets needed	Barber 1991, 119
Two tablets from burial at Dejbjerg bog, Jutland, Denmark.	Collingwood 1982

1–2 century BC (Petersen 1888;

Hald 1950)

Beechwood tablets. Cave at El Collingwood 1982

Cigarrelejo, Spain (Hundt 1968). 3

cm². 4 holes. 400–375 BC.

Accompanied by charred textile
with tablet woven starting border

Many Roman/Northern European Collingwood 1982

British tablets. 3–5cm. 1st–4th

century AD. Most bone, some

decorated, 1 bronze (Legionary

Museum Caerleon). 1 wooden

(Friesland Museum). Half are

triangular, may not be tablets.

Worn grooves suggest were used

with thread/rope. 1 has central

hole (Friesland). 1 has 6

(Alchester) (Behrens 1925;

Henshall 1950; Wild 1970). [Note:

only c. 40 tablets discovered, but

copious combs and whorls].

25 tablets, 4 cm², wood in Collingwood 1982

decorated ivory box, Coptic grave

Antinoe, Egypt. 4th–5th century

AD (Reuleaux 1902; Lehmann-

Haupt 1902). Never used

Other tablets also from Gayet Collingwood 1982

excavations. Similar date? 4th–5th

century AD

Roughly square bronze plate with Collingwood 1982

round corners and 4 holes. 6th

century grave. Oxfordshire. 2.5

cm². Pendant?

Bone tablet. Square. 4 holed. 7th Collingwood 1982

century burial. Kingston, Kent.

(Faussett 1856). Destroyed by fire.

Found with sewing implements

Bone tablet. 4 holes. Square. Collingwood 1982

Birka, Sweden. Assoc. with find of

tablet weaving. AD 900 (Geijer

1938)

Complete set 52 tablets. Still Collingwood 1982

attached to linen warp. Ship
burial Oseberg, Norway. AD 850–
900 (Grieg 1928; van Scheltema
1929). Wooden cask also had 3
tablets

Rectangular bronze tablets from Collingwood 1982
Anduln, near Klaipeda, Lithuania
'USSR', 99–10th century AD?
(Gotze 1908) 1.1–2.7 cm. Votive?
But with woven borders and
sewing implements

2 tablets. Bone. Square. 4 corner Collingwood 1982
and 1 centre hole. Boneworker's
workshop. Starom Meste,
Czechoslovakia, 'Great Moravian
Period' 9th century AD (Markova
1977; Stankova 1967)

4 hole. Tablet. Lund, Sweden. Collingwood 1982
Grave. AD 1200. (Olsen 1908; Bqt
1943). Runic inscription suggests
closer to AD 1000

Wookey, Somerset, Iron Age, Henshall 1950, cited in
Triangular, size 2 inches, 2 found, Collingwood 1982
3 holes, Wells museum (Arch.
Lxii, 582)

Alchester, Warwickshire, Roman, Henshall 1950, cited in
Square, Size (inches), 1½, 2 Collingwood 1982
found, 4 (6) holes, now in
Ashmolean. *Antiquaries Journal* 9
(1929), 134

Richborough, Kent Roman Square, Henshall 1950, cited in
1 2/5 inches, 1 found, 4 holes, Collingwood 1982
Richborough museum (Bushe-Fox
1949, 268)

Tain Ross-shire Midden Square, 1 Henshall 1950, cited in
3/8, 1 found, 4 holes, NMA Collingwood 1982
Edinburgh (HR 819) (*Proceedings
of the Society of Antiquaries of
Scotland* LXV, 353, 10).

Corbridge Roman Triangular, 2 1 Henshall 1950, cited in
7/8 inches, 2 tablets, 3 holes, Collingwood 1982
Corbridge, no ref.

- Keil Cave, Kintyre, Roman-British, Henshall 1950, cited in
Triangular, 2 inches, 1 tablet, 3 Collingwood 1982
holes, Campbelltown (Glasgow
Herald, 28 Sept.1935)
- Richborough, Kent, Roman, Henshall 1950, cited in
Triangular, 1 3/5 inches, 5 found, Collingwood 1982
3 holes, Richborough (Bushe-Fox
1949, 267)
- Silchester, Roman, Triangular, 1 Henshall 1950, cited in
1/2 inches, 2 found, 3 holes, Collingwood 1982
Reading, no ref.
- Woodcuts, Dorset, Romano- Henshall 1950, cited in
British, Triangular, 1 7/8, 1 Collingwood 1982
found, 3 holes, Farnham museum
(Pitt-Rivers 1888 xviii, 6)
- Wroxeter, Salop, Roman, Henshall 1950, cited in
Triangular, 2 inches, 1 found, 3 Collingwood 1982
holes, Wroxeter, (Bushe-Fox 1914,
16)
- Burra, N. Ronaldsay, Broch, Henshall 1950, cited in
circular, 1 1/4 inches diameter, 2 Collingwood 1982
found, 2 holes, NMA Edinburgh
(GB 236), *Proceedings of the Society
of Antiquaries of Scotland* X, 11)
- Jarlshof, Shetland, Broch, Henshall 1950, cited in
Circular, 1 1/4 diameter, 2 found, 2 Collingwood 1982
holes NMA Edinburgh (GA411)
museum, 2 holes, NMA Edinburgh
(GA 411) Broch is not an age, it's
a site.
- Unknown, no site, circular, 1 1/2 Henshall 1950, cited in
diameter, 1 found, 2 holes, Collingwood 1982
Hunterian, Glasgow (B 1914, 491)
- Oseberg ship Hansen 1990
- Dejbjerg. The tablets are square,
as are the somewhat later Danish
ones from the Dejbjerg find
Hansen 1990, 61
- Spanish Cigarralejo 'The earliest Hansen 1990, 61
tablets preserved are from
Cigarralejo in Spain and are 4th-
3rd century B.C.'

Peaked in Roman era with upright Hansen 1990, 62

two-beam loam. Includes

Thorsbjerg cloak, interwoven

border of 170 tablets, one of many

found in Nordic region.

‘single, small, almost square bone Walton Rogers 1997

plate’. No wear marks. Damaged –

discarded? Coppergate, York.

‘Most tablets are at least 30mm

square’ (Roes 1963, 149–150;

Wild 1970, 140–141; MacGregor

1985, 186, 191; Pritchard 1994).

Those in Coppergate were used for

delicate work

40 mm square, wood. Oseberg

Walton Rogers 1997, cited in

Grieg 1928, 180–1

Chapter 4

Romans, intimately. New thoughts on reconstruction and purpose of use of Roman Empire and Late Antiquity ‘tanga briefs’

Julia B. Krug-Ochmann

In February 2013, some well-preserved Roman leather briefs were examined by the author in the Museum of London and LAARC (The Museum of London Archaeological Archive). This formed part of the author’s PhD-project on trousers in antiquity. The finds are dated to the early imperial period to the 4th century. The European Textile Forum in Mayen, hosted in 2013, provided a golden opportunity for discussing possible reconstructions and thoughts on the way of wearing briefs –together with craftspeople who are experienced in working with historical textile techniques. The results of this discussion are partly incorporated into the following article.

For purposes of this article, ‘briefs’ will be used in preference to ‘pants’ as ‘briefs’ is a better description of the artefacts. ‘Briefs’ implies something that is tight and skinny without leg appendages, while pants may have joined legs.

The items

Analysing the seven imperial and late-Roman briefs from England in detail, together with two briefs known from Germany, would go beyond the scope of this article, so just a short overview will be given below. The items introduced in this article consist of seven leather ‘tanga briefs’ from London and another that was found in Trier. Two well-preserved briefs (Shadwell excavations and Queen Street) are already published in detail (Wilmott 1982, 52–55; van Driel-Murray

2002, 57–60). Some of the finds are in an excellent state of preservation, others are only in fragments. Because of the leather's fragility the edges of the briefs and their adherent laces are mainly destroyed. The laces can be compared to the strips of modern style bikini-slips. Their purpose is the same: to connect the (either one or two triangular) pieces of the briefs.

Cut and design of the briefs can be classified in two main groups:

1. The first type consists of two triangular pieces, representing the fore and reverse sides. The cut of the pieces is symmetrical and hour-glass in shape. The points of the briefs can be joined by lacing. Different variations might be possible: the lacing can be part of the briefs itself (so all material is cut from one piece of leather) or be attached. Furthermore the number of laces can vary. In most cases the briefs are decorated with geometrical patterns, arranged all over the surface. The ornamentation is made by several holes which are punched-out. With the exception of the Queen Street find, the edge borders (the cut edges of the briefs) of all briefs are not serged, since no stitches are visible.

2. The second type consists just of a frontside, cut from one single triangular piece of leather. The reverse side seems to be formed by a system of netted laces. The ornamentation of this type of briefs is homogeneous: the leather is open-worked by hexagonal punches. The pattern of two triangles upside down results from an arrangement of punched hexagons which stand side by side respectively above each other. Characteristic for this type is a single 'lace-hole' at the rightmost position of the briefs, most likely to support the lacing. The edge borders are not serged, no stitches are visible.

Reconstruction

At the European Textile Forum detailed examinations on two briefs, each representing a type, allowed elaboration of the most likely reconstruction. Due to their good condition one example from London and another one from Trier were most valuable. The examinations are based on technical analysis and partly on ancient depictions, namely two terracotta figurines from Egypt, dated to the imperial era. They represent the type of briefs that is known from Trier and London. Despite there being meager archaeological finds, the items below will be classified in two different types –due to ostensible analogies –called type I and type II.

The briefs from Trier ([Fig. 4.1](#)) were found in 1994 in the desiccated oxbow lake of the river Mosel (Goethert 2007, 60). They are now kept in the Landesmuseum Trier (Inventory number EV 1994, 161 Fnr. 273). They represent type II, briefs consisting simply of a triangular frontside and a system of netted laces at the reverse. Two other comparable examples ([Figs 4.2](#) and [4.3](#)) are known from London. They are kept in the LAARC (inventory numbers Low88_895 and Opt81_743) and are not yet published. Klaus-Peter Goethert provided some proposals concerning the reconstruction of the lacing from Trier (Goethert 2007, 61–62). His considerations are based on a mid 1st–early 2nd century terracotta figurine from Egypt, which is without dating and today kept in a private collection (Goethert 2007, [fig. 3](#)). An outline drawing of the figurine is given in [Figure 4.4](#). The terracotta depicts a woman with breastband and briefs –very similiar to the examples from Trier and London. The open-worked lattice-like forefront is in evidence and cleary visible. But the lacing, which is proposed by Goethert (2007, 61–62, [figs 2](#) and [4](#)), differs clearly from the crosswise lacing depicted on the terracotta figurine (shown in [Fig. 4.4](#)).



Fig. 4.1. Roman leather briefs, Trier, Landesmuseum, Inv.Nr. EV1994, 161 Fnr. 273

The first difference is that Goethert proposes metal inserts to hold and secure the lacing coming from the rightmost and leftmost position

of the briefs' frontside. The metal inserts are located lateral to the hips. From there the lacing is divided. One vertical strap is passing around the buttocks. Two other straps pass from the metal inserts alongside the lower gluteal muscle, connecting the sidewise fixation of the inserts with the briefs' crotch (Fig. 4.5). The second difference is that Goethert does not explain the crosswise lacing of the terracotta, which he proposes for his reconstruction.

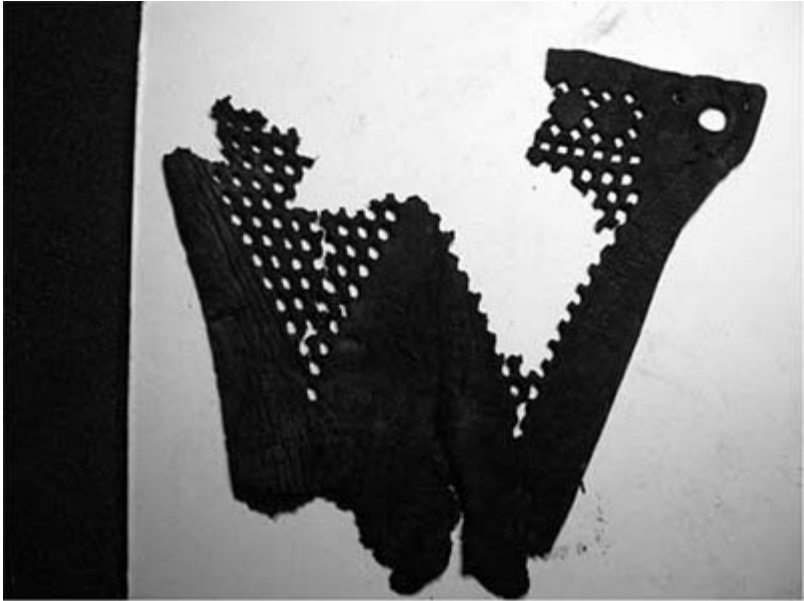


Fig. 4.2. Roman leather briefs, London, Museum of London, Inv.Nr. Low88_895 (photo J. Krug, printed with permission of the MoL)

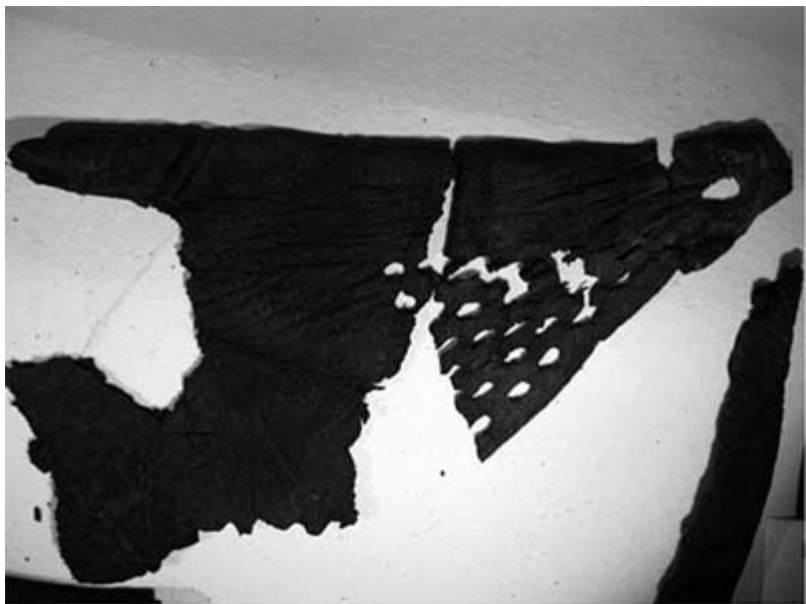


Fig. 4.3. Roman leather briefs, London, Museum of London, Inv.Nr. Opt81_743 (photo J. Krug, printed with permission of the MoL)

In fact the figurine is not suitable for reconstructing the briefs' reverse side, since the reverse side of the figurine is not elaborated. Goethert's reconstruction might be supposable, but is not verified by ancient depictions. Another terracotta figurine from Egypt, dated to Flavian or early Antonine period (mid-1st-early 2nd century), is more convenient for discussing the lacing ([Fig. 4.6](#)). The figurine depicts a nearly naked woman, except for black briefs. Since it appears to be an apparently pregnant woman, it is interpreted as fertility symbol. The dating is based on comparing the figurine's hair and face with mummy masks (Dunand 1979, 25, Kat. 107, pl. lvi). The crosswise lacing of the briefs is in evidence, in this case actually at the reverse side.



Fig. 4.4. Outline drawing of a roman terracotta figurine with breastband and briefs

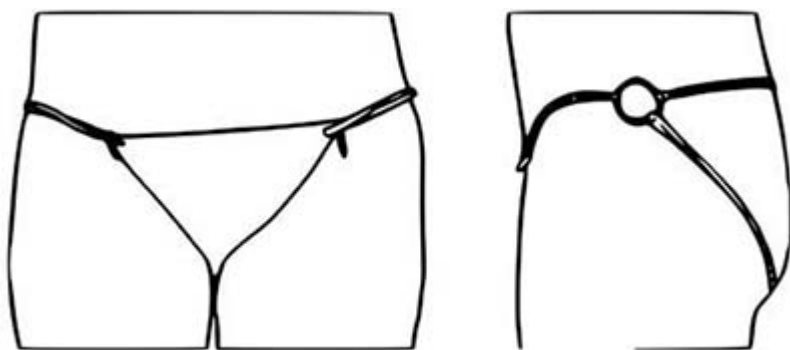


Fig. 4.5. Outline drawing of Goethert's reconstruction proposal

When looking at the original leather briefs in Trier (Fig. 4.1) the position of the straps becomes obvious. At the leftmost upper position of the briefs, the remains of a leather strap are visible. On the opposite edge no strap is visible, compared to similar findings from London (Figs 4.2 and 4.3) and it might be possible that there has never been any strap. Instead a loop at the edge was probably supposed to hold the strap from the opposite edge, after it has been passed around the hip. At the bottom of the briefs (crotch) three remains of straps are visible: one in each outer corner and one in the middle of the crotch. The terracotta indicates that at the figurine's back side a vertical strap connects the crotch to the upper horizontal strap. To secure the briefs in a comfortable position, the two other straps pass around the buttocks alongside the lower gluteal muscle, connecting the crotch with the upper horizontal strap. The figurine demonstrates that the connection of these straps is located at the hip.

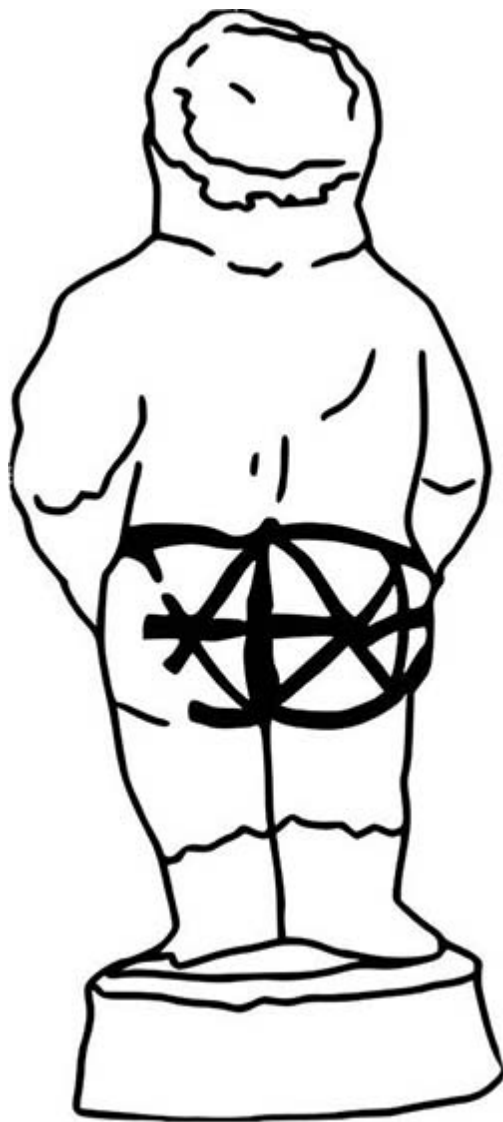


Fig. 4.6. Outline drawing of a roman terra figurine with brief

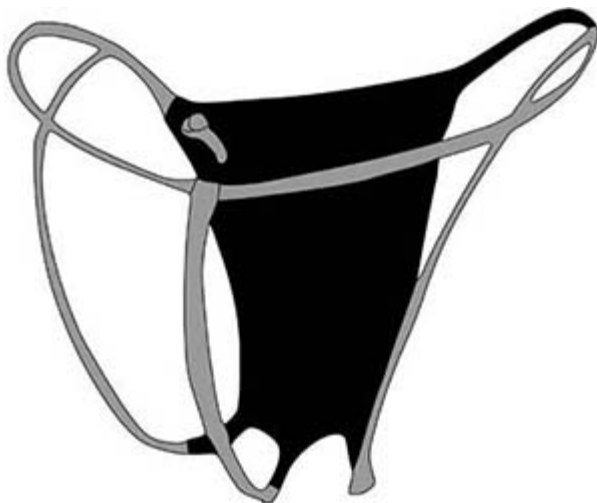


Fig. 4.7. Drawing of the reconstruction of briefs type II

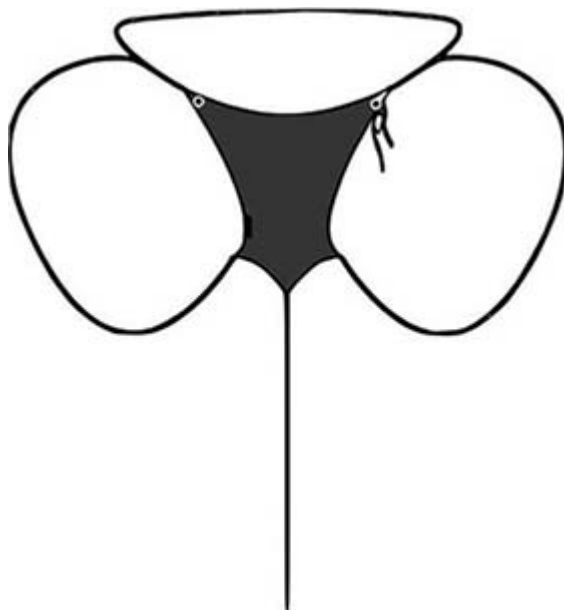


Fig. 4.8. Pattern of briefs type II

This arrangement forms the basic design of type II (Figs 4.7 and 4.8). Tests verified that the briefs do not slip and permit comfortable wearing. The crosswise leather straps are simply decoration, with regard to the briefs functionality, they are dispensable. Adding these straps is quite simple: by adding a further horizontal strap and two vertical ones (Fig. 4.9) the crosswise straps can simply be interlaced or stitched. Also a cut from one piece of leather, including the straps, might be supposable. A metal insert, as recommended by Goethert

(2007, 61), is not mandatory.

The loop at the frontside enables the briefs to be untied just at the rightmost upper corner (if we assume that the loop holds the upper horizontal leather strap). So the briefs go on and off very quickly. Contrary to all expectations, the complex-looking lacing of the briefs was easy to handle (Fig. 4.10).

The very well-preserved briefs from Queen Street represent type I (Fig. 4.11). The briefs, kept in the Museum of London (Inv.Nr. 21233), have a width of 38 cm (forefront) and at the backside a width of 48 cm. The length is 27 cm. They are composed of two triangular pieces, representing the fore and reverse sides respectively reverse sides, with hour-glass shape and symmetrical cut, joined by a lacing.



Fig. 4.9. Briefs type II with crosswise straps



Fig. 4.10. Briefs type II seen from the front



Fig. 4.11. Roman leather briefs, London, Museum of London, Inv.Nr. 21233 (photo J. Krug, printed with permission of the MoL)

The briefs were found in 1953 in a Roman well pit and are dated to AD 40–100 (Wilmott 1982, 52–55). The cut is symmetrical and from one single piece of very fine leather, the forefront is a little smaller. All edge borders are serged. The seam is not visible from the outside, because the stitch doesn't penetrate the leather completely –it is not possible to see the stitch from the outside. The thread is lost but must have been very thin, some marks are visible at the inside, the distance from stitch to stitch is 3mm, a very fine work! The grain side is outside. The briefs are in good repair; only the area of the right buttock shows major damage. It is remodelled with a second piece of leather. Although it is not mentioned in the report of restoration, traces of glue indicate a modern repairing. Some crinkles, most likely traces of wear, are visible within the crotch. The two strings, needed to fix the edges of the briefs, are not part of the briefs themselves, but cut separately and attached to the frontsides.

At first view there is no difficulty in trying to reconstruct the briefs. The cut doesn't differ from 'modern' briefs: to this day briefs with lateral lacing are widely used. But problems occurred during reconstruction: first briefs with identical measurements were cut from one piece of fine leather. Due to time constraints the lacing was attached by woollen strings, but the measurements remained unchanged.

Surprisingly the results showed that the briefs were much too small, even if taking the leather's assumed shrinkage into consideration (van

Driel-Murray 2002, 58). At the backside they just covered the buttocks at half-height. Problems also occurred at the frontside: the leather was distinctively bulged over the pubic area. The female model had a body height of c. 155 cm and equated to the average size of women from the 1st–3rd centuries AD as determined from bones excavated in miscellaneous Italian necropoli (Ruck 2007, 26, n 27). Therefore, a second piece was cut, this time the measurements were transferred to modern women's proportions. But the result was the same: here, too, the buttocks were not covered completely and the bulge at the frontside remained. But this is understandable. The pelvis needs a minimum width to enable childbirth. Although the size of the female has changed over the centuries, it is unlikely that the width of the pelvis would have changed significantly.

Trunks for men or ‘nappy pants’?

The facts mentioned above do not imply that women did not wear leather briefs. But they demand further considerations. Might it even be possible that briefs like the example from Queen Street were not only used by women? Male wearers should not be precluded, since we know from ancient literary sources (Krug-Ochmann in prep.) that men used to cover their private parts in fine black leather while having a bath. However, a test with a suitable male model contemporaneous to the tests at Mayen and using the same briefs showed that the buttocks were not covered either.

Another idea was formed within the scope of the European Textile Forum in Mayen: the problem with the misfitting briefs required consideration of alternative usage. Tests verified that the briefs were surprisingly suitable as ‘nappy pants’. A bolster was used as a ‘baby’, its dimensions conforming nearly to a toddler's body size. The ‘baby’ was laid down supine on the nappy pants which were closed by lacing up the two underneath sides. Then the pants were passed through the toddler's legs so that the genitals were covered. Finally the remaining sides were wrapped around the body and knotted at the backside. A knot at the back is more practical, since the toddler can not open it (Fig. 4.12).

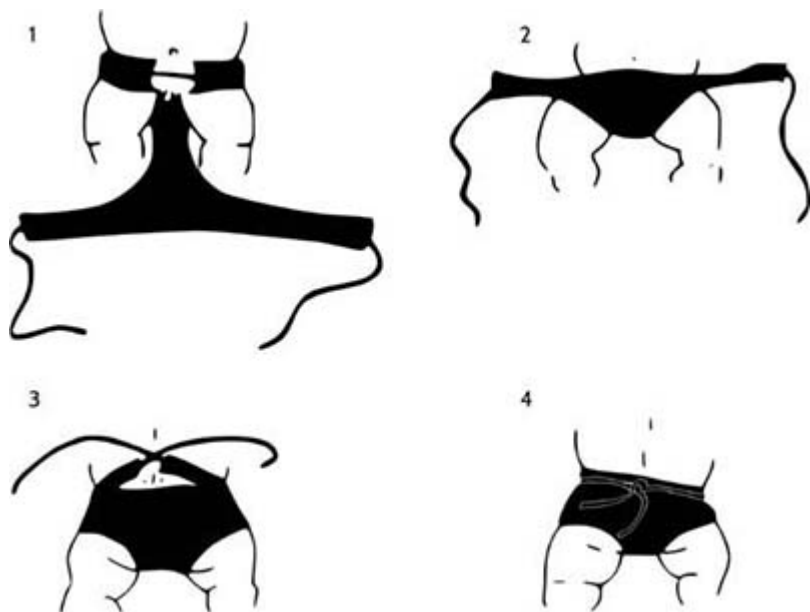


Fig. 4.12. Roman leather briefs as ‘nappy pants’, tested on a dummy

Some weeks after Mayen the author got the opportunity to try the nappy pants on an 13-month-old living toddler (Fig. 4.13). The child had a height of around 75 cm and a weight of 9 kg. The pants fitted barely, they should not have been much smaller. As newborn babies were swaddled completely in antiquity, as shown by ancient depictions (for example the nativity scene with the swaddled Jesus, depicted on the throne of Maximian in Ravenna), robust but soft nappy pants would, rather, have been useful for slightly older children, since children of this age learn to walk and are very agile. They need nappy pants that are secure on the one hand, but on the other hand ensure room to move. Today pants made of rubber are in use and still serve the same purpose.

Summary

The workshop allowed the reconstruction of two briefs, here described as type I and II. They represent two different patterns. The most important difference is that type I consists of two triangular pieces, representing a fore and reverse side, cut from one piece of leather, whereas type II is made of only one forefront. The reverse side is open and reduced to a system of laces. But this is sufficient to keep the briefs in place. Using the example of a terracotta figurine several attempts in arranging the laces led to a most likely reconstruction of type II.



Fig. 4.13. Roman leather briefs as ‘nappy pants’, tested on a live subject

Major difficulties occurred while reconstructing type I. Although the model’s size correlates to the average size of women from the 1st–3rd centuries AD, the briefs do not fit. The buttocks are not covered completely and the front is distinctively bulged.

This situation does not mean that women didn’t wear leather briefs, above all women wearing (apparently) leather briefs are known from ancient depictions. But the observed inconsistency stimulates the bringing forward of new ideas and other purposes should not be precluded. A suggestion which does not evoke any objections is the interpretation as nappy pants –although no ancient depictions of babies with nappy pants are known to date. Without question further investigation is necessary to discuss and answer open questions.

Acknowledgements

I am very grateful to Dr Katrin Kania for giving me the opportunity to participate in the European Textile Forum –LEA Mayen 2013. At this point I also would like to give my sincere thanks to Sabine Ringenberg, since she is Co-organisator of LEA Mayen. Also many

thanks to all participants of the European Textile Forum 2013 and their very creative ideas. Especially I want to express my gratitude to Dr Heather Hopkins for all her help and support. I am especially indebted to Caroline McDonald, Senior Curator of Prehistoric and Roman Collections at the Museum of London and all members of staff of the Museum of London for their great helpfulness and assistance during my research in the Museum of London. Many thanks also to Dr Klaus-Peter Goethert from the University of Trier for his help and vivid exchange of information. Finally I would like to thank my PhD adviser Prof. Dr Sabine Schrenk (University of Bonn) for her mentoring.

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Chapter 5

Linen sprang from Lengberg Castle

Beatrix Nutz

Introduction

In the course of extensive reconstruction, starting July 2008, at Lengberg Castle (Municipality Nikolsdorf, East Tyrol, Austria) archaeological investigations of several parts of the building were carried out under the direction of Harald Stadler (Institute for Archaeology, University of Innsbruck). During the research, a vault filled with debris and waste was detected in the south wing of the castle beneath the floorboards of room 2.07 on the second floor. The backfill was taken out by workers of a local construction company and stored for subsequent sieving, which took place in summer 2009. The waste consisted of dry material in different layers, among them organic material such as twigs and straw, but also worked wood, leather (mainly shoes) and textiles. The building history, according to notes in the itinerary of Paolo Santonino AD 1485, as well as investigations on construction techniques performed by Martin Mittermaier and Walter Hauser (Landeskonservatorat Tirol) and the archaeological features strongly suggested a dating of the finds to the 15th century. This date has now been proved by five radiocarbon dates carried out at the ETH (Eidgenössische Technische Hochschule) Zürich. It may be assumed that the vault was filled during the addition of the second storey as insulation or in order to level the floor.

The sprang fabrics from Lengberg

The textile finds stored at the Institute for Archaeology in Innsbruck consist of hundreds of fragments as well as a few almost completely preserved pieces. Among those are three undyed linen sprang fabrics, one used as a decorative element on a garment and two smaller

fragments whose original function is unknown, but they too were probably sewn onto garments. All three sprang fabrics were worked with S-plyed 2-ply yarn with thread diameters ranging from 0.5–0.7 mm and show hole designs.

The largest piece of sprang is one half of a sprang fabric sewn in between the two ‘cups’ of what is probably a headdress (Fig. 5.1, Inv. No. 01.02), initially thought to have been a ‘bra’ (Nutz 2013). But the attempt by Rachel Case at making a replica of the garment showed that the ‘bra’ version would not have fit, and it being a headdress is a much better solution. Pictorial sources support this interpretation.

Headdresses of this type were worn by men and woman and are depicted on various paintings and book illustrations. On three altar pieces –all showing the birth of the Virgin Mary –one female servant is wearing such a headcover.



Fig. 5.1. Linen headdress with sprang fabric in between the ‘cups’, overall view (photo: author)

a) Birth of the Virgin by the Master of Uttenheim, 1470-1480, tempera on wood, Nuremberg, German National Museum, Inv. No.

1180 (see [Fig. 5.11a](#)).

b) Birth of the Virgin by the Master of the 'Schottenaltar', 1469-1480, tempera on wood, Schottenstift, Vienna.

c) Birth of the Virgin by the Master of Mariapfarr, 1495-1505, tempera on wood, Parish Church, Salzburg.

A couple of men wearing this style of head covering can be found in book illustrations such as Hartmann Schedel's *Das buch der Cronicken vnd gedechtnus wirdigern geschichte[n]* published in 1493 ([Fig. 5.11b](#)) and the *Landshuter Ringerbuch* by Hans Wurm, c. 1490.

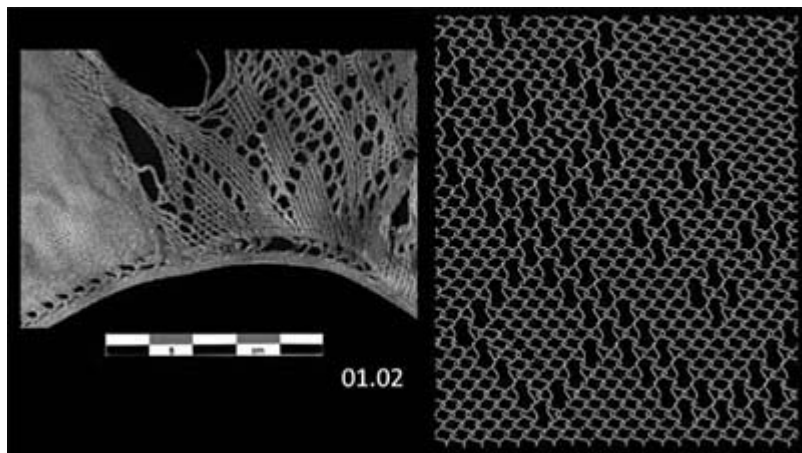


Fig. 5.2. Left: detail view of sprang fabric on headdress. Right: line drawing of threads (photo: author)

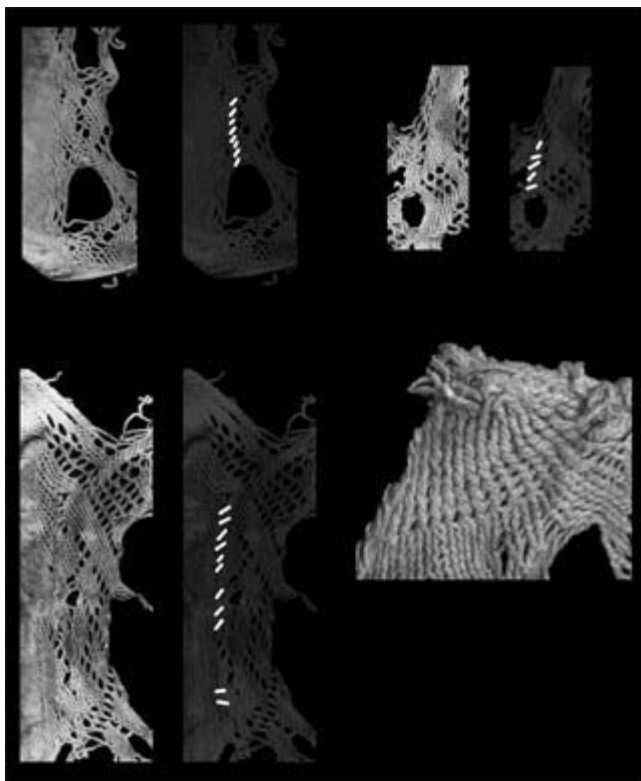


Fig. 5.3. Repair seams and ‘middle’ with sewing to prevent unravelling of sprang fabric on the headdress. The repair stitches are highlighted to the right of each detailed view with white lines (photo: author)

The sprang (see detail view on [Fig. 5.2](#)) consists of 120 warp threads and is worked by interlinking two warp threads at a time. The last seven rows were worked by interlinking four warp threads (two pairs), thus narrowing the fabric towards the middle. Three repair seams near the left and right edge of the fabric provide evidence of mending ([Fig. 5.3](#)). As the sewing thread used for mending is also an undyed S-plyed 2-ply yarn with an average diameter of 0.8 mm (compared to the 0.7 mm diameter of the plied yarn of the sprang) the repair is hardly noticeable. Today the fabric is rather damaged with multiple rips and holes, but taking the principles of sprang into consideration it is possible to reconstruct the pattern ([Fig. 5.4](#)), which shows that the holes (indicated as black hexagons) are not exactly reflected left and right, but this is not caused by the rips preventing a complete reconstruction as one might assume. The entire left side is missing a few vertical rows. Whoever made this sprang probably miscounted when warping the threads so the centre of the pattern does not equate to the centre of the fabric. This means he or she ran

out of threads to twist when reaching the left side to completely mirror the pattern. Although it would have been easy to add the missing warp threads after working the first row –that is when the worker would have noticed his or her error –he or she neglected to do so. This garment has been radiocarbon dated at the ETH Zurich providing a date range of AD 1390–1450 (ETH-40538: 510 ± 35 BP, probability 86.1%).

The second sprang fabric (Fig. 5.5, Inv. No. 246) is a fragment with a width of 22 mm (not stretched) and a preserved length of 11 cm. The S-plyed 2-ply yarn with a diameter of 0.5 mm is slightly finer than the yarn used for the sprang on the headdress. It was worked with 48 warp threads in hole design, the holes arranged in the shape of a flower being twice the length of the normal holes they are combined with (see Collingwood 1999, 148–149).

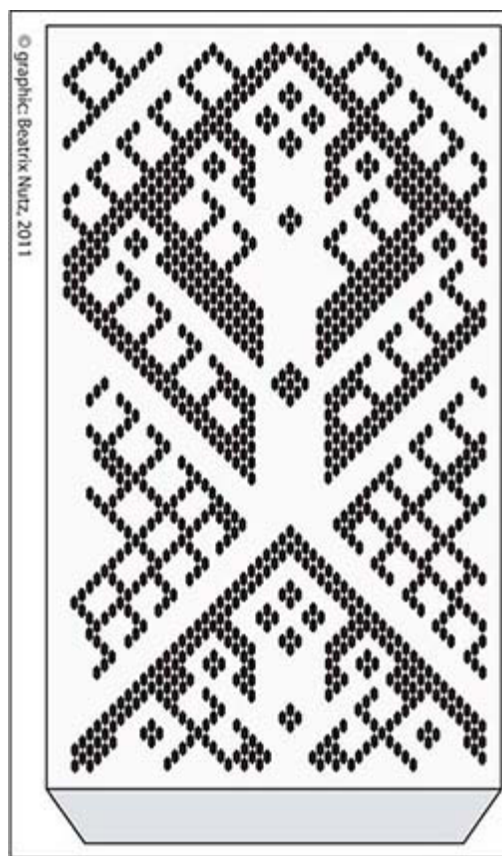


Fig. 5.4. Chart with reconstructed pattern of sprang fabric on headdress (drawing: author)

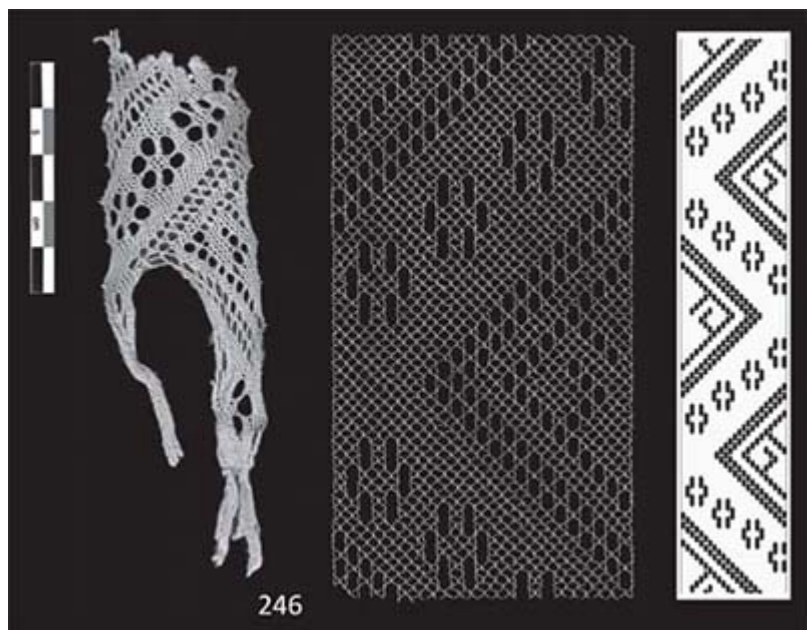


Fig. 5.5. Fragment of sprang fabric with 48 warp threads, line drawing of threads and chart of reconstructed pattern (photo and drawings: author)



Fig. 5.6. Fragment of sprang fabric with 32 warp threads, line drawing of preserved threads and chart of reconstructed pattern (photo and drawings: author)

The complete pattern of an even narrower sprang fabric (Fig. 5.6,

Inv. No. 343.11 and 522.05) of which two fragments have been found in the vault at Lengberg was worked with 32 warp threads. The fabric is torn lengthwise, now missing six to seven warp threads. The average thread diameter of the S-plyed 2-ply yarn is 0.6 mm. The smaller fragment is sewn on to a plainweave linen fabric of z-spun single yarn with thread diameters ranging from 0.3 mm to 0.6 mm and 13–15 threads per cm. The preserved lengths of the two fragments are 15 cm and 6 cm. Like the other narrow sprang fabric, this pattern shows holes worked in five rows combined with holes of twice the length worked in seven rows of interlinking.

It is not quite certain what the two narrow sprang fabrics were used for, but based on the fact that the larger sprang was part of a headdress, they too could have been sewn in between strips of woven fabric and their stretchy properties used for a headdress. Head coverings that look like as if there were narrow sprang fabrics inserted between woven fabrics are depicted in the *Landshuter Ringerbuch* by Hans Wurm (see [Fig. 5.11c](#)).

To date, only two more sprang fabrics dating to the 15th century are known. A wool fragment (42.5 × 35.6 cm) dating to c. 1450 – 1500 from London ([Fig. 5.7](#)), today housed in the Metropolitan Museum of Art in New York (Acc. No. 28.197) and a linen table cloth (320 × 75 cm) worked with a circular warp from central Switzerland dated 1400–1450 in the National Museum in Zürich (Inv. No. LM-22119; Schneider 1975, 73–74 and 232–233). Both fabrics are in hole design, the table cloth with leaf motif and diamond patterns with stylised lions, eagles, trees and geometric figures. The textile from London is one half of a sprang fabric, worked towards the middle to form a fringe.

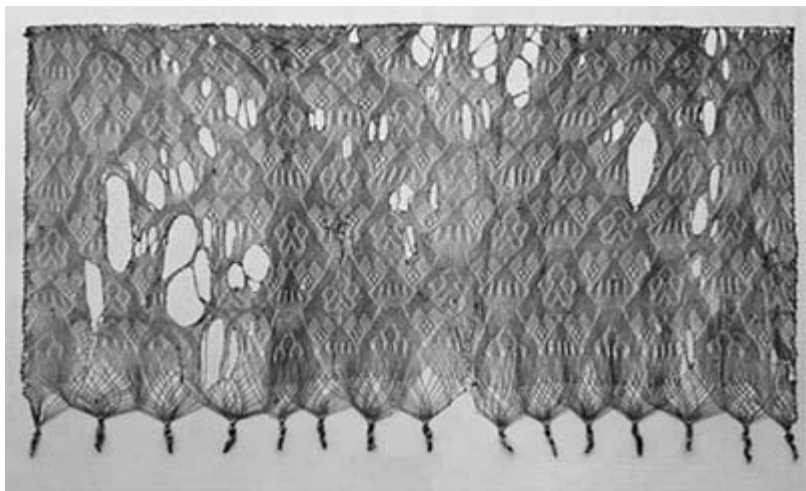


Fig. 5.7. Sprang fabric from London (© Metropolitan Museum of Art, New York: Acc. No. 28.197)

The patterns of the sprang fabrics from Lengberg Castle

A look at the reconstructed pattern of the sprang on the headdress reveals a tree-like design surrounded by fretwork. An almost identical tree with two birds at the foot of the tree was embroidered on an antependium with gobelin stitch (Dillmont 1890, 129–130) in drawn thread work (Dillmont 1890, 41) using white and blue linen thread. A fragment was re-used as reliquary. This textile from the abbey of the Benedictines in Engelberg, Switzerland, is dated to the 14th century (Schmedding 1978, 221–222). Another embroidered textile fragment from the same abbey, also dated to the 14th century, shows fretwork comparable to the one used on the Lengberg sprang (Schmedding 1978, 222). Fretwork patterns, (supposedly) designed for embroidery (Fig. 5.8), can also be found in one of the oldest European pattern books by Peter Quentel, printed in Cologne in 1536 (Quentel 1536). This proves that certain decorative styles were in fashion over an extended period of time as the textiles from Engelberg and Lengberg are approximately a century older than the book by Peter Quentel and that he simply printed some very old patterns although the book title reads *Ein new kunstlich Modelbuch* (*A New Artful Pattern Book*). It also demonstrates that grid patterns can be executed in more than one way and that patterns thought to be used in embroidery can very well be used in sprang too. The patterns of the two smaller sprang fabrics do not reveal a certain style.

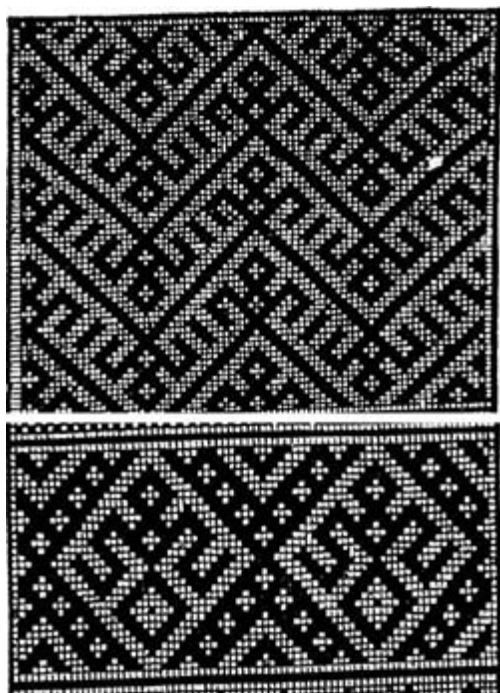


Fig. 5.8. Pattern from the pattern book by Peter Quentel (1536)

Reconstructing the patterns

The greatest challenge of this study was to reconstruct the pattern of the sprang fabric on the headdress. It is torn in many places, making it difficult to count the number of warp threads used and to determine the exact pattern. Knowing the principles of sprang helps in this regard. The warp threads of a hole design should preferably be dividable by four and a reflected pattern, as is the case with all three sprang textiles from Lengberg, should look the same on the left and right side and needs the same number of warp threads for both sides. Of course this is not the case with the larger sprang on the headdress due to an error during warping, but the rule in general still applies. These rules help with reconstructing the pattern and drawing the chart: areas where the sprang is too ripped to see and count the twists might still have the undamaged reflected image on the other side, which can then be used for reconstruction.

Written and pictorial sources of late medieval/early modern times sprang production

The finds from Lengberg raise the question whether sprang is mentioned in medieval written sources such as account books or inventories.

The word 'sprang' that we use today to name this technique is of Scandinavian origin, originally meaning an openwork textile. In an inventory from a guild in Hamburg (northern Germany) *spranck* is mentioned, which may also be related to our modern word (Collingwood 1999, 34 and 44). Peter Collingwood lists a number of medieval written records from northern Europe from 1328–1578, but no central or southern European sources. So what about southern Germany and Austria? To date no written records relating to sprang could be detected for this region, but it may be because we do not know what this type of work was called in the 15th century. In a book published in 1800 in Leipzig the technique is referred to as *Rahmenstricken* (= frame knitting) or *Greifstricken* (= pick knitting). The chapter begins:

Das Rahmenstricken ist vorzüglich in der Schweiz gebräuchlich, wo es das Greifstricken heißt, weil die Faden bloß mit den Fingern unter einander gegriffen werden. Es wird dazu eine Maschine in Gestalt eines länglichen aufrecht stehenden Rahmens erfordert, wie sie auf Tab. XV abgebildet ist. (Netto and Lehmann 1800, 32)

Translation: Frame knitting is primarily used in Switzerland, where it is called pick knitting, because the threads are only picked up with the fingers. This requires a machine in the shape of an oblong rectangular upright frame, as depicted in Tab. XV.

Should it indeed be that the word *stricken* (knitting) was used to describe sprang fabrics as well as (in modern terms) actually knitted ones, we will not be able to distinguish between the two.

By the 20th century the technique was all but forgotten in most central European countries, but even in some of the countries with an unbroken tradition of sprang production, there is no distinct name for the technique. In Slavic languages such as Czech, sprang is also called knitting (=pletení) on a frame (=rámu) or loom (=krosien) or knitting without needles (=pletení bez jehlic) (Kindlová and Tomková 2001; Mihalic 2013; Kielbusová 2014).

In French publications (Paulis 1930; 1933) and on museum websites (e.g. the Cinquantenaire Museum in Belgium) the technique of sprang is named *le point de dentelle* which translates to 'lace stitch', but this

does not help with the search for German sources.



Fig. 5.9. Fresco at Sveti Primož, Slovenia, dating to 1520 (© Institut für Realienkunde –University of Salzburg)

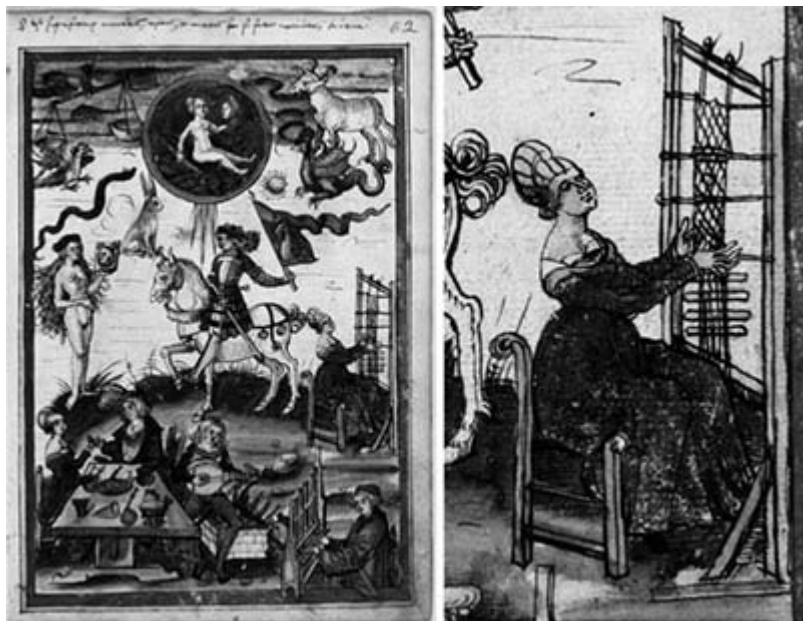


Fig. 5.10. Woman sitting at a sprang frame (detail right). Pen drawing

painted with watercolours The Planet Venus and her Children, Upper Rhine, early 16th century. (© Bibliothèque Nationale Paris, Ms. Allemande 106, fol. 62r)

The search for pictorial sources found geographically closer to Lengberg yields more results. A church fresco in Slovenia dating to 1460 shows a woman sitting in front of a free-standing frame on which threads are stretched vertically and her hands are in a working position common for sprang. Another, more detailed church fresco at Sveti Primož, also in Slovenia, dating to 1520, depicts the Virgin sitting in front of a sprang frame (Fig. 5.9; Schweitzer 1966). Also, from the beginning of the 16th century is the book illustration *The Planet Venus and her Children* in a manuscript (Fig. 5.10) from the Upper Rhine (region between Basel, Switzerland and Bingen, Germany). The woman sitting at the sprang frame seems to be working on an open fabric, maybe a hairnet (Drinkler 2010, 19).

The sprang textiles from Lengberg, together with the pictorial sources, prove that this technique must have been quite common in Central Europe in the 15th and 16th centuries. Maybe with the help of the knowledge that it might have been called ‘knitting’, further research will offer more results in regard to written sources.

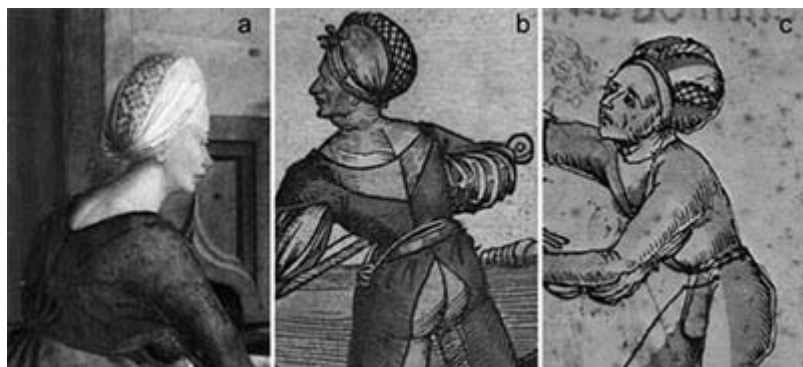


Fig. 5.11. Head coverings with possible sprang inserts. a) Birth of the Virgin by the Master of Uttenheim, 1470–1480, from: Pacher 1998,168; b) Executioner from Hartmann Schedel, Das buch der Croniken (http://daten.digital-e-sammlungen.de/bsb00059084/image_232); c) Wrestler from Hans Wurm, Landshuter Ringerbuch (http://wiktenauer.com/wiki/File:Wurm_2.jpg)

Conclusion

Unless more sprang fabrics dating to the 15th century are found,

either in future archaeological excavations or in museum depositories (where there might be some that just have not been recognized as sprang) the textiles from Lengberg, London and Switzerland are the only existing actual sprang fabrics. Some sprang textiles depicted on paintings, like the (possible) sprang cap of Jacob Fugger (c. 1519) and the cap of St. Eustachius on the Paumgartner altar (after 1503) both painted by Albrecht Dürer, or tapestries (e.g. the sprang cap of a man on the tapestry 'The Hunt of Emperor Maximilian', Brussels 1531–1533), today in the Louvre, may be studied and to some extent even reconstructed, but essential information for exact replicas (the fibre used, yarn diameters etc.) will always be missing. Whether or not Renaissance hose on paintings, whose patterns suggest they might have been worked in sprang (as Dagmar Drinkler suggests in Drinkler 2010) were indeed worked in this technique will most likely remain a mystery. The surviving sprang fabrics as well as the fabrics on pictorial sources that can be clearly identified as sprang are made with hole design. This however does not apply to the bi-and multi coloured Renaissance hose. Even European sprang fabrics from later centuries like a French purse dating to 1775-1800 (Pietsch & Eikermann 2013, 130) and the sprang garments in the Cinquantenaire Museum in Belgium are in hole design. Therefore sprang in hole design must be considered as the standard European sprang type until further notice.

Acknowledgements

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Chapter 6

Early Byzantine embroidery techniques and an unusual tunic in the Römisch- Germanisches Zentralmuseum Mainz

Petra Linscheid

Early Byzantine textile finds

Textiles are rare in the archaeological record, since organic materials survive over the centuries only under special conditions. The dry and hot climate in Egypt is especially suitable for the preservation of textiles. The finds from Pharaonic Egypt constitute the oldest assembly of textiles. The material which came to light in Egypt is also our main source of evidence for the Roman (31 BC– AD 395) and Early Byzantine (AD 395–640) period. Tens of thousands of textiles were retrieved from graves belonging to the Late Antique and Early Byzantine period. For a long time classified as ‘Coptic textiles’ and disregarded as provincial production, it is nowadays widely accepted that the textiles found in Egypt reflect and represent the clothing and furnishing fabrics of the entire late Roman and Early Byzantine Mediterranean world (Granger-Taylor 1987, 23; De Moor and Fluck 2011).

Nearly all of the textiles were found in graves. In the 3rd century AD, burial customs in the late Roman world changed. The deceased were no longer burned or wrapped naked in bandages, but were buried in their daily life costume. Often they were wearing several tunics, one over the other, and spare clothing for the afterlife was laid in the grave. Curtains, wall hangings or covers were used as shrouds and the deceased was occasionally resting on cushions. These clothing and furnishing fabrics were not manufactured especially for burial, but they were previously used in life, which is testified by repairs and traces of wear in the textiles.

These tens of thousands of textiles –mainly fragments –from Early Byzantine Egypt are housed in European and North American public collections. They were acquired mainly from unprofessional and undocumented excavations undertaken at the end of the 19th/beginning of the 20th century by private explorers and collectors. The early excavations provided us with many textiles but, unfortunately, the collectors were not interested in an archaeological documentation of the finds. The textiles were collected without recording the archaeological context, so data about the find spot, the gender and age of the deceased as well as the associated grave-goods were missing. Often the decorated parts of the textiles were cut out from the ground weave at some point. Consequently, most of the Early Byzantine textiles in public collections today are unclear as to their provenance, their dating and often even their original appearance and function.

Early Byzantine textile techniques

In Early Byzantium, the following raw materials were used: linen (flax), sheep's wool, goat hair, silk and cotton. It is the opinion of many scholars that already in Late Roman times the warp-weighted loom was replaced by the vertical loom with the warp stretched between two beams (Wild 2003, 143).

The weaves used were tabby weave, twill, damask, taquete (weft-faced compound tabby) and samit (weft-faced compound twill), as well as looped pile fabrics. About 95 % of the known textiles, garments as well as furnishing textiles, consist of a linen or woollen ground weave in tabby, which is not patterned all over, but only in special areas. The standard patterning technique for the decorative bands and panels is tapestry weaving (Fluck *et al.* 2000, 13).

Tapestry is basically a tabby weave, replacing the ground weft with differently coloured weft threads according to the pattern. The wefts in tapestry have to be inserted in great density in order to cover the warp, which is usually of a different colour to the pattern. Consequently, tapestry weaves possess a repp-like structure. The wefts in tapestry consist usually of wool, since wool may be dyed easily, linen may not.

Among the large number of textiles found in graves of Early Byzantine Egypt, there is only a small proportion of garments and furnishing textiles decorated with embroidery. Embroidery may be defined as a patterning by additional stitches into the ground weave after the process of weaving. The stitches do not contribute to the construction of the textiles, but they are for decorative purpose only.

There are two techniques popular in Early Byzantium and looking similar to embroidery: Brocading and the so-called 'flying shuttle'. Brocading as well as the flying shuttle are based on additional threads floating according to the pattern. Brocading is the patterning of a fabric with additional weft threads, floating over a few binding points in weft direction. The so-called flying shuttle consists of an additional, usually light-coloured linen thread floating on the surface of the cloth and used for line drawing in tapestry. In contrast to brocading, the flying shuttle allows pattern lines that run independently of warp and weft direction, and thus looks very similar to embroidery. Just like brocading, though, flying shuttle is executed during the process of weaving. Embroidery instead is done after the weaving process on the finished cloth.

In textile analysis, a thorough examination of the patterning thread is needed to distinguish between brocading, flying shuttle and embroidery: if the patterning thread is lying exclusively in the sheds, it is brocaded or a flying shuttle. An embroidery thread instead will sooner or later damage a thread of the fabrics warp or weft system. Observing a patterning thread damaging warp or weft threads is thus a clear evidence for embroidery.

The tunic with embroidered decoration in the Römisch-Germanisches Zentralmuseum Mainz

The weave

In the collection of the Römisch-Germanisches Zentralmuseum Mainz (RGZM), there is an exceptional tunic (Acc. no. O.22708, [Figs 6.1-6.2](#)), with decoration produced exclusively by embroidery (Linscheid 2016, 57-59, cat. no. 1.; Volbach 1932, 114). The tunic is preserved more or less completely. During a conservation treatment by Brigitte Dreyspring in the year 1996 the tunic was mounted on a white linen support.

The tunic was acquired by the RGZM at the beginning of the 20th century from the Coptologist Carl Schmidt, Berlin, with the indication *Friedhof des weißen Klosters bei Sohag* ('Graveyard of the White Monastery near Sohag'). Unfortunately, there is no evidence for this provenance. Radiocarbon dating by the Curt-Engelhorn-Zentrum für Archäometrie in 2013 yielded the time span AD 407-537 (Lab code: MAMS 16812; Age BP: 1604 $\pm$ 26; cal 2 sigma (95.4 %): AD 407-537) as dating for the tunic. So the tunic is firmly placed in the

Early Byzantine Era.

The front and back of the tunic measure 80 cm and 95 cm respectively in length, the lower width is 104 cm. The sleeves are 25 cm long and 15 cm in width. The warp and weft threads consist of linen yarn, S-spun, thread diameter 0.2–1.0 mm, with 14–20 threads/cm in the warp, and 10 threads/cm in the weft. The warp threads are paired in irregular intervals. The weave is tabby. The warp is running horizontally in all parts of the tunic, the weft vertically. The preserved edges indicate that the tunic was woven to shape, as was the rule in Early Byzantium.

There are selvages at the lower horizontal edge of side A (Fig. 6.1), and at the horizontal edges of the sleeves. In waist height of side A and B, there is a horizontal seam joining the upper and lower part (Figs 6.1–6.2). The tunic was obviously woven to shape in three pieces: The upper part of side A and B including the sleeves was woven in one single piece with a selvedge at the lower horizontal edge. The lower parts of side A and B were woven separately and attached to the upper part by a seam.

Weaving a tunic to shape in one single piece required a loom at least two metres in width. For weaving a tunic in three pieces a much narrower loom was sufficient. As De Jonghe and Verhecken-Lammens (1993, 43) pointed out, the lower parts of the tunic could still be woven on the same warp.

The tunic shows traces of modern damaging and manipulation: The lower horizontal edge of side B is cut. The sleeves were manipulated as well: they were cut from the body, probably shortened and attached again to the shoulder area by sewing.

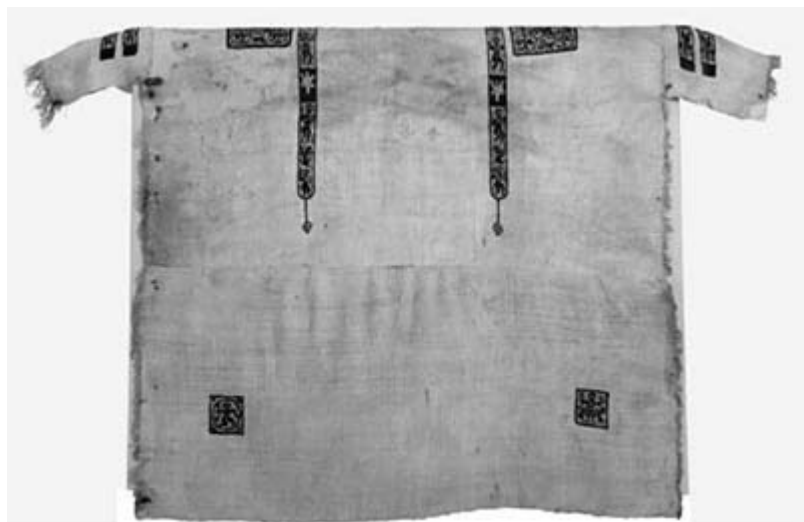


Fig. 6.1. Tunic RGZM Mainz, acc. no. O.22708, side A (© RGZM Mainz, photo: V. Iserhardt)

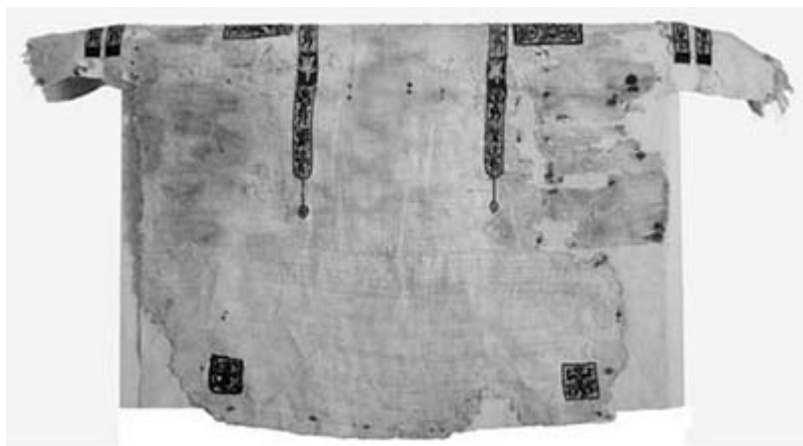


Fig. 6.2. Tunic RGZM Mainz, acc. no. O.22708, side B (© RGZM Mainz, photo: V. Iserhardt)

The embroidered decoration

The tunic is decorated in the typical scheme of Early Byzantine tunics: two clavi (width: 3 cm, length: 24 cm) on front and back side, two rectangular shoulder panels (11 × 11 cm), paired sleeve bands (width: 2.5 cm) and rectangular panels at knee height (6 × 6 cm).

All these decorative panels are worked in embroidery with violet wool (slightly Z-plyed from two S-spun yarns, thread diameter 0.7-1.0 mm) and undyed linen yarn (S-spun, thread diameter 0.2-0.7 mm) (Fig. 6.3). The stitch used is couching stitch (Schutte and Müller-Christensen 1963, 11, fig. 17; Wade 1981, 17-18). A single violet plied thread was laid on the surface of the cloth for a short length and then ‘couching’ or tied down with the same thread in overcast stitching (Fig. 6.4). This stitch was used in this tunic for filling larger areas as well as for lines. After the embroidery with the violet thread was accomplished, a white linen couching stitch was laid on the embroidered areas for additional line drawing.



Fig. 6.3. Tunic RGZM Mainz, acc. no. O.22708, detail from the clavi (© RGZM Mainz, photo: V. Iserhardt)

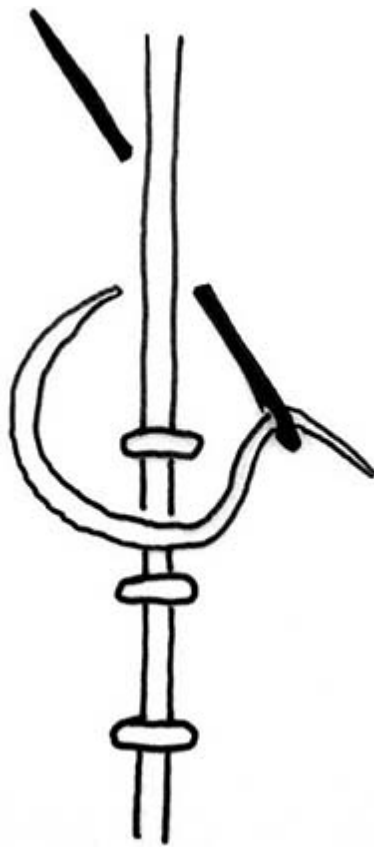


Fig. 6.4. Couching stitch (drawing P. Linscheid)

During the 2013 Textile Forum conference, the embroidery was reproduced by Katrin Kania. The couching stitch proved to be a timesaving and economical working technique by wasting as little thread as possible on the reverse side of the fabric. Since the violet thread is plied very loosely, it provides additional volume to the embroideries.

The clavi, shoulder panels and sleeve bands of the Mainz tunic show warriors or hunters with shield and weapon. In between are depicted running animals (Fig. 6.3). In the clavi this sequence is interrupted by a violet panel with a blossom. The square shoulder panels present a central roundel with a rider. The layout of the embroidered decorations as well as the pattern itself mirror standard tunic decorations in purple-coloured tapestry, see for example a linen tunic in Nantes, Musée Dobrée (Santrot *et al.* 2001, 70). Monochrome, purple-coloured tapestry panels mostly are enriched by the ‘flying shuttle’, for drawing details or delicate patterns (Verhecken-Lammens

2013). In the embroidery of the tunic in Mainz, this ‘flying shuttle’ is imitated by the white linen couching stitch.

Patterning by discolouration

The embroidery of the tunic in the RGZM Mainz reveals another unusual patterning method. Some figure details like shoes, shields, or ends of tails are highlighted by a light brown and turquoise colour which was not produced by introducing coloured threads, but by a discolouration of the violet threads after the process of embroidery (Figs 6.3 and 6.5). The centre of the discoloration is coloured light brown turning to turquoise at the border. Probably these discolourations are imitating red colour accents woven with red weft threads and appearing occasionally in Early Byzantine purple-coloured tapestries (Fluck *et al.* 2000, 113).

Similar discolouration patterning effects have been observed by Annette Schieck on some tapestry panels in the Deutsches Textilmuseum Krefeld (Paetz gen. Schieck 2013) and by Roberta Cortopassi on a tapestry in the Benaki Museum, Athens (pers. comm. 9 Oct. 2013). This discolouring technique is rare and little known so far, but considering its spread, it seems to be an antique patterning method rather than a modern manipulation.



Fig. 6.5. Tunic RGZM Mainz, acc. no. O.22708, detail from the clavi with discoloration in the upper left (© RGZM Mainz, photo: V. Iserhardt)

Discussing this phenomenon during the Textile Forum 2013 conference, Sabine Ringenberg presumed the discolouration to result from applying a special substance that influences the colour, on the finished embroidery. These substances could be mordants or substances that bleach or alter the colour in the wool. A first trial with ammonium and sodium dithionite on wool dyed with madder, tannin and indigo did show some discolouration, but not with results similar to the discoloration in the originals. These first tests did lighten the colours a little, but not significantly, and there was no change in the actual colour such as the originals show. However, after this promising start, further investigation in both the dyes used for the original discolour-patterned tapestries and embroideries and methods of discoloration would be worthwhile.

An unfinished tunic

There are several details indicating that the embroidered tunic was not finished. First of all: the tunic does not posses a neck-hole, instead a green thread is marking the line where the slit for the neck-opening was intended to be cut.

Another detail for the unfinished state of the tunic is the simple overcast stitching at waist height joining the upper and the lower part of side A and B. This seam is not strong enough to fix the lower part of the tunic during wearing and therefore one should expect an additional run-and-fell seam of some centimetres in width, as it appears regularly with tunics woven in three pieces (Fluck *et al.* 2000, 45). Furthermore, there is no sewing, neither at the sleeves nor at the sides of the tunic.

Although this tunic was not finished, it was put into the grave of a deceased person as is testified by the marks of criss-cross bandages running from the upper half of side A to the upper half of side B. Obviously the tunic was spread out like a shroud on the deceased and wrapped with the typical criss-cross bandages around the body.

Why an unfinished tunic was put into the grave of a deceased person and if this might be a reason for the unusual decoration techniques of embroidery and discoloration remains open for speculation. Was the embroidery eventually done by the deceased him-/herself as a domestic technique replacing tapestry? It would be worthwhile researching, if the enclosing of unfinished works in grave goods was a common practice in Byzantium and what this practice might reveal about the idea of afterlife.

Comparable tunics with embroidery

As mentioned above, tunics with embroidered decorations are rare. Fifteen examples were treated recently by C. Fluck (Fluck 2011). Nearly all of these tunics are –like the example from Mainz –linen tunics with monochrome embroidery. Eight were found in the Kharga Oasis, at the sites of El Bagawat and Dush (Fluck 2011, 79–80) and date to the period 3rd–4th centuries AD. The tunic from Dush was recently treated again by F. Letellier-Willemin (Letellier-Willemin 2013).

As far as technical information is available, these embroideries differ from the tunic in Mainz by using stem stitch, running stitch and overcast stitch. These embroideries are imitating purple-coloured tapestry weave as well (Fluck 2011, 78; Letellier-Willemin 2013, 32) but the additional white linen thread imitating the flying shuttle is missing. Furthermore, the decoration is concentrated on the breast and back area of the tunic and includes linear and isolated figures. The design of the latter takes advantage of the easy linear drawing in embroidery, which on the contrast is hard to do in tapestry weaving.

The embroidery of the tunic in Mainz is closer instead in technique and style to a group of four embroidered linen fragments which are housed in Rome, Musei Vaticani (Acc. no. T 88; Fluck 2011, 81) and the Musée du Louvre (Acc. nos E 28890, E 28909, AF 5714; Mérat 2013, 126–131). These fragments are embroidered in couching stitch, imitating tapestry decoration and the flying shuttle as well. At least two of these fragments were found at Antinoupolis and are radiocarbon dated to AD 425–565 and AD 412–536 respectively (Laboratoire de Mesure du Carbone 14, E28890–244; age BP 1559 +/–28; 95.4%. Laboratoire de Mesure du Carbone 14, E28909–243; age BP 1603 +/–22; 95.4%,. See Mérat 2013, 127), a date going together well with the date of the RGZM tunic. At least the fragments in Rome and one of the fragments from Antinoupolis in Paris (Acc. no. E 28890), can be identified as parts of a tunic because they show the characteristic twining of warp threads for strengthening the neck opening (Fluck *et al.* 2000, 52).

A fragment with embroidered decoration in the BLM Karlsruhe

A fragment in the Badisches Landesmuseum Karlsruhe, acc. no. T 9 (Linscheid 2017, 91–92, cat. no. 149.), findspot unknown, presents a

different type of embroidery than the tunic in Mainz (Fig. 6.6). The fragment consists of a tabby linen weave, 36×11 cm in size, warp and weft direction cannot be determined. Both thread systems are linen, S-spun with thread diameter 0.2–0.3 mm resp. 0.3–0.5 mm and a weave density of 16–18 and 24–26 threads/cm respectively.



Fig. 6.6. Fragment Badisches Landesmuseum Karlsruhe acc. no. T 9 (© BLM Karlsruhe, photo: Th. Goldschmidt)

The fragment is decorated with an embroidered band, executed in violet and pink wool, with plied yarn s-s > Z, the pink thread partly z-z > S, thread diameter: 0.5–0.8 mm. The embroidery is worked in satin stitch, also called flat stitch (Schutte and Müller-Christensen 1963,

10–11, fig. 13; Wade 1981, 1) (Fig. 6.7). Since the stitches are floating on the surface and since the thread is plied, especially the hearts are appearing three-dimensional on the surface of the fabric (Fig. 6.8). Thin lines instead are embroidered in stem stitch. Although there are comparable tapestry weavings which might have served as a model (Wulff and Volbach 1926, 20, Acc. no. 9113), the white linen thread imitating the flying shuttle is missing.

Since both sides of the fabric show the same stitches, it is undeterminable which side was the front and which was the reverse side of the object. The satin stitches are not as economical as the couching stitches, since they use the same length of thread on both sides of the fabric. Is this a hint to a double-sided use of the fragment?



Fig. 6.7. Satin stitch (drawing P. Linscheid)

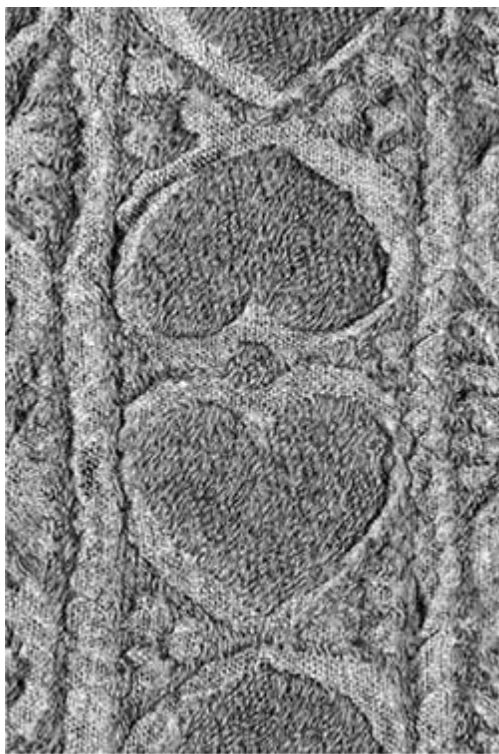


Fig. 6.8. Fragment Badisches Landesmuseum Karlsruhe acc. no. T 9, detail (© BLM Karlsruhe, photo: Th. Goldschmidt)

The original context and function of the fragment is not clear. At the left edge of the fragment there is a run-and-fell seam running along the whole height of the fragment and joining the piece with a similar, probably identical, linen fabric. Since this seam is partly overlapping the embroidery, it must have been sewn after the embroidery was finished. If the seam is a construction seam or else a repair remains unclear.

The stitches used, the lack of the flying shuttle imitation as well as the design and the colours of the fragment in Karlsruhe are close to the above mentioned tunics found at El Bagawat and Dush. Instead the Mainz tunic and its comparable pieces in Rome and Paris constitute another group due to their embroidery technique and decoration. The difference between the two groups may be a chronological or else a geographical one. The group around the El Bagawat/Dush tunics embroidered in stem stitch date to the 3rd/4th centuries and originate in the Kharga Oasis (Fluck 2011, 83). The group of the Rome, Paris and Mainz embroideries in couching stitch is younger, dating to the early 5th-mid-6th centuries, and originating, as far as proveniences are known, to the Nile Valley.

The question of pattern sheets

The question is still open as to the way in which the patterns were transferred into embroidery on the ground weave. On a linen fragment from Early Byzantine Akhmim, Egypt, depicting a cross embroidered in chain stitch and couching stitch with coloured wool threads, there is a drawing of the pattern visible in the areas of wool loss (London, Victoria and Albert Museum, Acc. no. 1262-1888, see: <http://collections.vam.ac.uk/item/O141442/embroidery-unknown/> [12.12.2014]). On the fragment in Karlsruhe, there are no traces of a drawing, although in several areas the embroidery thread is lost, showing the bare linen ground. The pattern must have been transferred from a pattern sheet directly into embroidery, or a non-permanent method for drawing the pattern was used. On the tunic from Mainz, the linen ground underneath the embroidery is not visible to enlighten this question.

Summary

A tunic from Mainz, RGZM and a fragment from Karlsruhe, Badisches Landesmuseum, represent two different techniques and styles of Early Byzantine embroidery. Both embroideries are imitating tapestry weaving. The embroidered tunic in Mainz, being in an unfinished state and serving as a grave good, raises the possibility that embroideries are domestic techniques to replace the more skilful and more expensive tapestry weavings. On the other hand the discoloration effect which could be observed on that tunic required a considerable skill and knowledge. The questions as to who created the embroidery, who discolored it and in which way this effect was achieved cannot be answered with satisfaction at this point. Nevertheless, the unusual techniques add to our knowledge of Early Byzantine textile production.

Acknowledgements

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Chapter 7

Late Antique resist-dyeing technique

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Background and technical data

Resist-dyeing is a specific method of applying colours to fabric: A substance that is impervious to the dye and blocks it from the fabric is painted on certain areas of the fabric, while other parts are free to take up the dye colour. This technique was already in use in Antique times, as the surviving resist-dyed fabrics show.

A number of examples of this technique survive from antiquity. The oldest fragments probably are woollen fragments from a huge blanket, found on Taman peninsula (opposite the Krym) dating to the 4th century BC (Gerziger 1975). However, most items are from Late Antique/early medieval times (3rd–6th/7th century), often from Egyptian findspots. They feature designs painted on linen, using an un-identified resist substance. Today more than 40 of these textiles are known, most of them dyed blue, in more rare circumstances also dyed red. Some are of considerable size, such as the so-called Dionysos hanging in the Louvre in Paris (1.30 × 3.47 m) and the so-called Artemis hanging in the Abegg-Stiftung in Riggisberg, Switzerland (1.94 × 6.00 m). While some of the fragments might be the remains of clothing, most of the pieces are interpreted as parts of large curtains or (wall-) hangings. The size of the motifs also hints at this use: figures are often shown in nearly life size.

The motifs themselves span a wide range of topics. For example Artemis, the Greek goddess of hunting, is represented in her typical fast movement in front of a small temple (Fig. 7.1). She is accompanied by mythological hunting heroes such as Adonis and Meleager on one side. On her other side, hunting scenes are depicted. Other motifs are scenes from the life of the mystery–and wine–god

Dionysos, as well as detailed stories from the Old and New Testament and many other topics. The motifs thus include pagan, Christian and secular themes and add a lot to the knowledge of late antique monumental paintings.

All scenes and ornaments, for example tendrils holding or framing little animals (Fig. 7.2), are painted with great routine, indicating the work of a professional well versed in this technique and familiar with tools and materials. As to the quality of these representations, the vivacity of the figures, the variety of the ornaments and the dense and intricate compositions are surely on a par with wall paintings of the time. However, these textiles allow a completely different insight into the medium of painting as well as into the wide field of room furnishings. The technique of resist-dyeing creates patterns that are clearly visible on both the front and the back of the fabric. This makes them very well suited as curtains or as hangings with a structural function, for instance for dividing rooms. These are functions for which archaeology has no other evidence at all.



Fig. 7.1. Detail of so-called 'Artemis hanging' in the Abegg-Stiftung,

Despite the beauty of resist-dyed textiles, relatively little attention has been paid to them so far, especially concerning the technical details of the dyeing process. A preliminary test regarding possible resist substances was inspired by a discussion of these fabrics between the authors, Sabine Schrenk from the Department of Christian Archaeology, Bonn University, and students from this department, one of whom is writing a PhD thesis about this subject.

While dyeing animal fibres such as wool or silk is possible with a very large number of plant and insect dye substances, most of these dyes require an additional preparatory step, the mordanting procedure. Mordant dyes bind to the fibre through an interconnection of the metal salts from the mordant to the fibre and work much better on animal fibres than on plant fibres. Dyeing linen using historical methods works best with vat dyes, which have a different underlying chemistry. The vat dyes known best are indigo or woad, though true mollusc purple is also a vat dye that is chemically related to indigo (Schweppe 1993, 290–294). This corresponds to the very clear, intense and well-preserved colours of the resist-dyed textiles from linen, where dyeing red would have been much more expensive than dyeing blue.



Fig. 7.2. Detail of the so-called ‘Dionysos hanging’ in Paris, Louvre, Dept of

Modern resist-dyeing techniques are mostly known in the form of European blue printing, where a resist paste is applied to the fabric using printing models, and in the form of batik that is traditional in several Asian countries. While the resist paste used in European blue printing consists of entirely different materials, batik typically uses wax as a resist substance. The well-known Indonesian batik technique makes use of a special instrument, the *tjanting*, to apply hot wax to the fabric. It is also possible to apply the wax using brushes or printing blocks.

In literature about resist-dyed late antique textiles, there is often mention of a mixture of resin and wax used as the resist paste (as for example in Flury-Lemberg *et al.* 1995; Schrenk 2002). Unfortunately, there are no documented residues of resist pastes on the textiles, and we thus lack any analysis that could shed light on the substances actually used. Despite this, the use of resin and wax has become a *communis opinio* in literature and is therefore repeated frequently.

It is not easy to trace, however, where this idea of a wax-resin mixture comes from. Most of the texts do not mention a source or reference. Robert Forrer supposed in his work about printed textiles, published in 1894, that the substance might be wax (Forrer 1894, 10), and the same is true for Ormonde M. Dalton in 1911 (Dalton 1911, 602). Only much later, the assumption of a mixture of wax and resin can be found in the literature. One possible explanation for this assumption might be a direct transfer of the medium used for encaustic painting to the application as a resist substance on textiles.

The materials used for the Egyptian mummy portraits – a specific representative of antique encaustic painting – have been an area of interest since the eighteenth century, and analyses of the paint medium have been attempted for almost as long. For a painting of Cleopatra, an early analysis gave two-thirds resin, one-third wax as the result (Sartain *et al.* 1885, 21). Results of the analyses differ widely, and there is speculation as to the use of heat during or after the painting to melt the paint, additional solvents such as naphta oil, and the mixture of wax and resin. The earlier works about the composition of encaustic paints seem to favour the theory of a use of wax and resin, sometimes with very high resin content. Theories as to the application of these paints include the use of volatile solvents such as naphta oil, such as given by H. Hansen in his paper ‘The development of new vehicle recipes for encaustic paints’ (Hansen 1977). Other, more recent analyses, have yielded different results,

including the probable use of un-modified beeswax or wax treated with alkali (the latter leading to a saponification and thus water-solubility of the wax; see Ramer 1979). A wax-soap mixture was found to be the most probable vehicle in a more recent paper (Cuní *et al.* 2012).

Two facts, however, oppose the direct transfer of encaustic technology evidenced by mummy portraits to the use as resist substances in textile dyeing. The first is the dating of the mummy portraits as opposed to that of the textiles –resist-dyed textiles from Egypt are known from the late antique period (3rd–6th century AD), and the pieces considered as the basis for this experiment are all dated to the 4th–6th centuries AD. Recent work on the mummy portraits led to the now widely accepted suggestion that the portrait production saw its peak already in the 2nd century AD, followed by a dramatic decline and its end around the middle of the 3rd century (Borg 2010). While this date difference does not exclude the use of similar techniques and materials, the lack of a significant overlap from the periods of the mummy portraits and the resist-dyed textiles rather discourages the theory of a technology transfer.

The second fact in opposition to a direct technology transfer is the great difference in the intended nature of the substances used for painting as opposed to those used as resist substances. The aims of mixing an encaustic paint vehicle are firstly to obtain a substance that will hold the pigments and securely attach them to a painting ground, secondly to mix the paint medium so that it can be applied as required, and thirdly so it will set into a durable, brightly coloured final painting. The addition of resins to beeswax will lead to a more brittle, but also more durable final result (cf. Hansen 1977).

For the application of a temporary dye-resist substance, several requirements have to be fulfilled but they are quite different from those applicable to encaustic paint medium:

- The substance has to work reliably as a resist substance, blocking the dyestuff from staining the fabric. The substance, when applied, thus has to penetrate the fabric thoroughly enough to prevent the dye liquid from entering the fibres. It also has to stay in the fabric during the dyeing process without cracking, dissolving or otherwise disintegrating. The substance should also be relatively inert in regard to chemical reactions with the fabric itself as well as the dyeing chemicals.
- It has to allow application with appropriate tools such as brushes or possibly special instruments for hot-wax application. While freehand application is by far the most common application technique, the

possible help of models, stencils, or printing blocks of some sort was used at least in some cases, for instance in the borders of some textiles (Illgen 1968). The resist substance thus needs to be useable with these tools as well.

- It has to be possible to remove the resist paste after dyeing with a method available to the textile workers in Late Antique Egypt. This method must not damage the textile or the resulting dyed colour. This is the decisive difference in regard to the encaustic painting medium, which is intended to be as long-lasting as possible.

Regarding the first requirement for a working resist substance, the process of indigo dyeing takes place within a relatively small temperature range. This is due to dyestuff reactions. When dyeing wool with indigo, a minimum temperature of c. 50°C for the dye bath is often recommended in dyeing instructions (for instance Kircher 1982; Sandberg 1989). Traditional dyeing of blue printing, however, is done with a cold dye vat, so heating up the liquid seems not to be necessary. The maximum temperature of the dye-bath is limited to 60°C (Schweppe 1993, 290). Explanations of why these temperatures are recommended are limited or non-existent.

Beeswax is a complicated mixture of substances that can differ depending on the bee species, the region and the age of the wax comb. Therefore it is not possible to rely on a fixed melting point of the wax (Fröhlich 2000, 53). In a study on wax properties of *Apis mellifera carnica* Pollm. the transition of different waxes between phases was found to vary by between 18°C and 25°C for all three transitions (two solid-solid transitions and one solid-liquid transition, compare Fröhlich 2000, 58). While the melting point of beeswax is usually stated to be around 64°C, the material undergoes a broad transition when slowly heated, starting to melt significantly earlier, at about 40°C (Buchwald *et al.* 2008, 122f). This means that traditional melting point measurements may be considerably higher than the true onset of melting. Furthermore, the melting point for a given wax may be different from the average melting point, even if contaminants etc were removed.

If the wax used for a resist-dye pattern gets too hot, it can lead to discolouration of the wax, and it also might mean possible deterioration of the pattern. Even if the melting point of beeswax in warm regions may be higher than that of Middle European bees, it is still possible for this effect to occur. Theoretically, the addition of resin may have been supposed as a possibility to stabilise the beeswax in higher temperatures.

In the Roman Empire, resin was a well known –and used –resource.

Besides cultic, cosmetic and medical use, resin was applied in different kinds of trades such as cooperage, preservation and encaustic painting. For cultic, cosmetic and medical uses, redolent resins such as olibanum and myrrh were used, and Pliny mentions their very high price (Plin. Nat. 12, 70ff). Since redolence is not a feature necessary for a resist substance, it is more likely that, in case resin was added, cheaper materials were used for this purpose. In encaustic painting of Egyptian mummy portraits, the resins of shellac and stone-pine are known to be part of paint mixtures (Ramer 1979, 1–13). It therefore seems possible that these resins were also used for resist-dyeing textiles.

Shellac is a substance derived from the raw lac produced by the female lac-insects. The geographic range of these insects is India, Cambodia, the Moluccas, Thailand and Sumatra. (Schweppe 1993, 272–275) The melting point of shellac is given at 65–85°C (<http://www.dmsshellac.com/specifications.html>) or 77–80°C (Bartholomé 1976, 537). Shellac can be dissolved in alcohol as well as in alkaline watery solutions. Typically, shellac also contains up to 6% waxy substances. It has a saponification value of 220–230, indicating that 220–230 mg of potassium hydroxide are necessary to saponify 1 g of shellac. When heated above 100°C, it hardens and becomes a non-melting substance that is indissoluble in alcohol (Bartholomé 1976, 537).

Pine resin may have been derived as gum resin from the species of pine native to Egypt, the Stone Pine (*Pinus pinea*). Fresh tree resin (gum resin) is a viscous substance consisting of non-volatile solids dissolved in volatile fluid components, the terpenes. Pine resin can be used for both the manufacture of rosin (colophonium), the solidified resin without terpene components, and turpentine. Turpentine is one of the substances that dissolves beeswax, but is rather volatile. The solid colophonium is a glass solid rather than a crystalline solid, and has a softening point usually in the range of 70–80°C (Coppen and Hone 1995, 43). Gum resin is soluble in most oils as well as in alcohol, and has a saponification value of 172 (Bartholomé 1976).

Adding fresh raw or filtered resin to the beeswax may thus have significantly different effects than adding rosin to the wax; if alkaline water components are added to the mixture, again much different effects may result due to saponification.

Finally, the resist substance has to be removed after dyeing. There are no resist substance residues known or analysed to this date; the complete lack of resist substances can be interpreted as evidence for the full removal of the paste. Several different methods of removal are

theoretically possible, ranging from the application of heat and absorbent materials to draw the molten substance out of the fabric to removal using chemical procedures in a wider sense.

Experiment design

As sources regarding the mixture, use and removal of resist substances in Late Antique textiles are virtually non-existent, experimental archaeology can be used to gain some impression about the feasibility and suitability of beeswax as well as wax-resin mixtures as the resist substance for dyeing linen. In more recent times, resist substances for dyeing techniques were both waxes as well as other, water-soluble pastes as known from blue-printing of textile. An immersion in the aqueous dye bath is made possible by sufficiently long drying time for the resist substance. Since there is the frequent mention of wax-resin-mixtures in literature concerning the late antique resist-dyed textiles, the aim of this experiment was to test the application and removal of mixtures of wax and resin.

While the experiment can give no proof about the actual use of a given substance or mixture, it is a first test of whether different mixtures of beeswax with the two kinds of resin used in encaustic painting, shellac and *Pinus* resin, are more or less suitable than pure beeswax as a resist paste for dyeing linen with indigo. As with all other craft processes, it can be safely supposed that there was not one single 'true' recipe, but instead many different methods, tools and substances were used, depending on region, workshop and workshop tradition, and individual craftspersons. This is also evident when looking at the encaustic paintings, which – as described above – show different paint medium mixtures.

The main points of interest during the preparation of this experiment concerned the heat and water resistance of the resist substance during the dyeing process, the possible chemical changes of shellac when heated as part of the wax mixture to more than 100°C, and the ease or difficulty in removing the substance from the textiles after dyeing, using methods with plausible availability for the given time and area. The method of application is left out of consideration to limit the time and material needed.

Preparation

For the experiment, pure linen fabric with a thread count of approximately 11/17 threads per cm, roughly similar to that of the textile finds mentioned in the beginning of this paper, was chosen.

The piece was prepared for dyeing by boiling it for a good 15 minutes in de-ionised water to remove any residues of size or other contaminants.

The experimental resist substances were defined in accordance to the different analysis results or hypothesis regarding the encaustic paint substances. Due to time restrictions, it was not possible to test punic wax together with the wax and wax-resin mixtures. It was also not possible to test different variations of stone pine resin; only fresh resin was available. The available resin was fresh resin taken from a stone pine in the Botanical Garden Bonn; the resin sample consisted of more and less fluid parts and also contained bits of dirt and bark residues.

Resist substances were set to be pure beeswax (#1) as a reference as well as two different ratios of beeswax and resin: 22.2 g beeswax to 2.75 g resin (shellac #2, pine resin #4) and 20.8 g beeswax to 4.1 g resin (shellac #3, pine resin #5). For preparation of the resist substances, a temperature-controlled heating unit for batik wax was used. To prevent contamination of the substances, the heater was lined with aluminum foil.

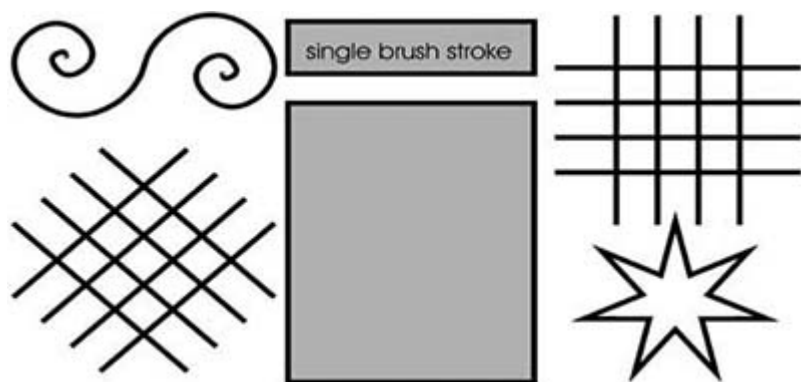


Fig. 7.3. Pattern for the test applications. The two fields in the middle were painted on with a brush, the thinner lines on the right and left drawn with a tjanting

The stone pine resin was prepared by first melting it in a closed glass jar in a water bath to equalise the resin consistency; it was then transferred into the wax heating unit and the worst of the impurities were removed during the molten stage. The resin was then left to cool, hardening in the process. For mixing the resist substances, wax and resin were measured out on precision scales; both were put into the heating unit simultaneously. Temperature was controlled with help of

an inserted thermometer.

When heating the beeswax and shellac of mix #2 together, the shellac clung to the bottom of the heating unit. The shellac and beeswax were both molten at c. 70°C, however it was not possible to mix the shellac with the beeswax at all. Since it was not possible to get an applicable wax-resin mixture in this way, neither mix #2 nor mix #4 were applied to the textile.

Application of the resist substances was done with both a tjanting and a brush. The tools were heated in the resist substance in the wax-melting apparatus to keep everything at as even a temperature as possible. The temperature of 115°C was chosen for this purpose. The commonly recommended application temperature for waxes in modern batik is 110–120°C to ensure good penetration of the wax through the fabric. This penetration is necessary to properly reserve the fibres. For the application, a motif with both thin lines, applied with a tjanting, and solid resist-painted areas, applied with a brush, was used (Fig. 7.3).

Dyeing

After application of all three resist substances, the fabric pieces with the three different resist substances, plus one reference piece without resist substance, were dyed with indigo. For the dyeing process itself, the modern vat-dyeing technique for indigo with sodium dithionite as the reduction agent in the vat was used. This method, developed in the 19th century, is suitable for both vegetable and animal fibres, is much easier to control than fermentation vats and is the main method in use today (see also Balfour-Paul 2004, 84f). The recipe was taken out of a modern book with recipes and instructions for plant-dyeing (Kircher 1982, 82f). The dye vat was prepared using the amounts of chemicals for about 500 g of wool fibre for the linen fabric (weight 100 g) to ensure there would be enough dye in the liquor; 12.5 g indigo were used for this. Two blank vats of 2.5 l each were prepared. For the dyeing process, 100 ml of the stock solution were added to each blank vat and stirred very carefully. Samples 1–4 (beeswax) and the reference fabric were dyed together in one of the vats, while the samples 5–12 (beeswax and resin) were dyed together in the second vat. Dyeing and oxidation process were each set for half an hour, which reliably brings good results with wool yarn and wool fabric; dyeing temperature was kept at 45–50°C in all three vats. For the dyeing process, three immersions of 30 minutes duration, followed by 30 minutes oxidation time, were carried out.

Contrary to the experimenter's expectations, there was no strong

gain of colour after the second and third immersion in the liquid. While the fabric seemed rather dark and with a strong contrast between the light-coloured resist paste and the fabric background while wet, the textile appeared much lighter after drying (Figs 7.4 and 7.5). All three resist pastes furthermore showed signs of being dissolved slowly during the dyeing procedure. Therefore it became clear already during the dyeing stage that with this method, it would not be possible to achieve the strong colour contrast between reserved fabric and dyed fabric that is evident in the originals. After the last oxydation, the fabric was inserted into a slightly acidic bath of de-ionised water and essence of vinegar to neutralise the alkaline dye bath.



Fig. 7.4. Test patch #2 after the last immersion, still wet



Fig. 7.5. Test patch #2 after the last immersion, dry

Removal of resist substances

The resist pastes were removed using four different procedures, one physical method and three chemical. The physical removal of the pastes was attempted by ironing the pieces of fabric, sandwiched between suitably absorbent paper, with a household iron set to full heat. The paper was changed as necessary. Removal of all three resist substances was possible with equal ease up to a certain degree; a remainder of wax stayed in the fibres. Heat alone thus proved not to be effective to remove all the resist substance from the textile. This corresponds to modern batik process instructions, where ironing is just the first stage of wax removal (cf for example Belfer *et al.* 1992, 48ff). After ironing, white reserved spots and parts where the resist substance had been applied very thickly were visible, while other reserved areas seemed a darker blue, due to the residual wax.

The second method of removal was heating the test pieces in de-ionised water. For this, each piece of the test fabrics was placed into a laboratory jar with 1 litre de-ionised water at room temperature. The water was then heated. The piece with #1 started to lose some of the wax at about 45°C, while the other mixtures started to come off at about 68°C. There was not too much discernible difference in the process apart from these different starting temperatures; at a water temperature of c. 80°C, all pieces seemed quite clean.

The third sample batch was placed into 1 litre of cool de-ionised water with 2 g of olive oil soap added and dissolved in the water. Olive oil soap is a detergent that could have plausibly been used in 4th–6th century Egypt; natron suitable for producing soap was

available from several places in Egypt during the relevant time-span (for a summary of natron sources in Egypt, see Shortland *et al.* 2006), and cultivation of olive trees in Egypt as well as oilmaking is confirmed for the Panopolis region in the 4th century (Bagnall 1996, 50). While other fats as the basis for soap-making are a definite possibility, olive oil soap is still widely available today and thus a suitable choice in regards to reproducibility of the experiment. The liquid was heated, as before. All three samples started releasing the resist substance from the fabric at about 50°C and seemed to be clean at around 70°C. The sample with beeswax was taken out once between 50° and 70°C to get an estimate on how much of the wax was already removed from the fabric, then placed back into the liquid as there were still considerable amounts of wax left on it. The water of all three samples had a noticeable greenish tinge to it, partly due to the colour of the soap which was a dark brownish yellow, partly due to indigo particles removed from the fibres.

As the final removal test, the samples were immersed in an alkaline watery solution of 1 litre de-ionised water with 10 g of potassium carbonate (K_2CO_3) added. Both the wax and the resins can be saponified in an alkaline environment, at least for the most part. The solution was gently warmed to c. 40°C to speed up the saponification process. In this test, the beeswax showed better saponification and better removal from the fabric compared to the other methods.

All pieces that were immersed in liquids for the removal of the resist substance were rinsed and then dried. There were colour changes noticeable in the pieces depending on the different methods used for removal. All of the pieces showed better contrast between the reserved parts and the unreserved parts when wet; upon drying, most are uniformly blue with the exception of small spots where the resist substance was applied very thickly (Fig. 7.6). This is due to saponification of the resist substances in the warm alkaline dye bath during the long immersion times.

Additional testing

While the effect of saponification may be successfully used to remove the resist substance, its occurrence during the dyeing process was unwanted and proved to be a major flaw in the experiment design. In addition, the long immersion in the dye bath did not result in the expected depth of colour for the fabrics, in spite of a very generous amount of indigo in the bath.

A second dyeing process was made with a scrap piece of the experiment linen that had been used to test the applicators for the

resist substances before applying it to the test linen. This time, the linen was gently lowered into the cold indigo bath and then immediately removed again for the oxidation process. Dip-dyeing in this way was repeated multiple times until a deep blue colour was achieved; the resist substances showed the first beginnings of saponification, but not enough to significantly influence the pattern on the fabric in the way the longer immersion dyeing had done (Fig. 7.7). The resist substances were removed by pouring boiling water over the piece of linen. This method also proved successful. Both the depth of the colour as well as the reserved designs in this additional test proved to be much more satisfactory than in the experiment proper.



Fig. 7.6. All test patches after removal of the resist dye substance, fully dry

Result summary

The experiment showed that both pure beeswax as well as beeswax with added pine resin in ratios of at least up to 1:5 can be used as a resist substance for resist-dyed textiles. Of course, this does not exclude the use of other resist substances for the manufacture of the Late Antique textiles. Removal of the wax and wax-resin mixtures was comparatively easy.



Fig. 7.7. Dip-dyed linen with resist substance still on. In the background for colour comparison the experiment test patches (photo: Julie StOrup)

The experiment clearly showed that the dyeing method which is reliably successful for wool is not suitable for linen fabric, especially not in combination with a wax-based resist-dyeing technique. A more suitable vat for dyeing linen is described in the dyeing instructions given for vegetable fibres by Sandberg (Sandberg 1989, 129–133; unfortunately, this book was not available to us during the planning and design phase of the experiment.).

It also became evident that saponification of wax-based resist substances in the dye bath can be a problem; alkalinity, temperature and length of immersion are the three main factors that will influence this saponification, and the dyeing process must take these in account to successfully produce textiles with clear contrasts and a deep colour.

With the more successful dyed piece of the additional test, it is now possible to compare the resulting lines with the design of the actual late antique fabrics. This might help with further evaluating whether wax-resist techniques or other resist substances were used in the manufacture of the textiles. Further tests in this direction might also help in getting an idea about the tools and methods used for application of the resist substance. For a better survey, more

experiments will probably be necessary to compare the dyeing results of resist substances based on clay, similar to blueprinting substances, and wax-based resist substances with each other and with the original fabrics.

An analysis of the different resist-dyed textiles regarding not only their image topics, but also their workshops, styles and technique of painting as well as their function is currently in progress for a dissertation project at the Christian Archaeology Department, University of Bonn. Looking more closely at these fascinating textiles showed that the explanations in current literature regarding tools and techniques of their production were surprisingly vague, and that in some instances, important questions, such as questions regarding the application of the resist pastes and the dyeing procedures have not been asked yet. Some of the gaps in the research became obvious when planning and running the resist-dyeing experiment at the Textile Forum in Mayen 2013, and it is now clear that much more research will be necessary – including a deeper look into literary sources regarding available substances such as beeswax, resins, and oils, as well as a different and more focused look at the technical details of the preserved textiles such as possible evidence for brush strokes or characteristic application traits of other tools. Studying more carefully, and with new questions and points of view developed through the practical experiences, will be a challenge for the future.

It remains to say that this experiment also shows how restricted resources as well as incomplete knowledge of a craft process can influence an archaeological experiment negatively. For the planning phase of the experiment, relatively little time was available due to a number of unforeseeable circumstances. This meant no time for preliminary tests to gain familiarity with the resist technique and substances, or with the dyeing technique. It also curtailed the possible research both of sources regarding the availability of materials in Late Antique Egypt and of contemporary techniques and methods for resist-dyeing with indigo.

Preliminary tests to evaluate a more suitable method for dyeing linen with indigo may have yielded much better results and a much better comparability of the dyed sample pieces than the method employed. Better knowledge of the properties of shellac may also have resulted in the exclusion of this type of resin straightaway, since it does not dissolve in beeswax without the aid of additional solvents. Even though saponification of the resist paste was considered as one possible method for its removal, it occurred to none of the persons involved with designing the experiment that this saponification would

start happening in the warm alkaline dye bath.

However, the preliminary tests regarding resist substances possibly used for the textiles from Egypt, like many other archaeological experiments before this, show us that we can still gain valuable insights even from an experiment that might be considered as partly or completely failed. This includes a better insight into which questions to ask next, and how to design the following experiments. And it also includes the insight that the craftspersons of the past must have been highly skilled and highly knowledgeable to achieve the results evidenced by the surviving textiles – pieces that are not always appreciated as the spectacular finds that they are.

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Chapter 8

The influence of metal kettle materials on the mordanting and dyeing outcome

Katrin Kania, Heather Hopkins and Sabine Ringenberg

Introduction

While the dyestuffs used in antiquity and history are getting much attention, there is much less research being done on the importance of the mordant and the many and varied factors that influence the outcome of dyeing with a given natural dye. The results of any dyeing process using natural dye can vary a lot, depending on the mordant, the quality of the plants used for dyeing, the raw material, the thickness of the yarn or the cloth, the twist of the yarn and even the quality of the wool itself. In addition, the quality of water, dyeing temperature, the presence or absence of chalk/ calcium and any other chemicals present will influence the colour.

An often overlooked, but nevertheless very important, factor for the outcome of the dyeing process is thus also the kettle itself. While modern dyers can use chemically neutral, inert dye vats constructed from laboratory glass, enamelled pots or stainless steel, these materials were not available in medieval or ancient times. Copper and iron kettles do have an influence on the resulting colour, as is well known to modern plant dyers (cf. for example Kircher 1982, 14). Their exact influence is not easy to tell, since they are just one factor among several others. Following earlier investigation of the operating methods of the Roman dyeing industry, a series of experiments were undertaken at the LEA to establish the influence of the metal mordanting and dyeing kettle on the dyeing outcome.

Background

Hopkins' study of the dyeing industry of Pompeii gave an estimated

size and scale, through embedding modern experimental archaeology and computer simulation within an understanding of the classical sources and physical remains (Hopkins 2007; 2008; 2013a). This challenged the original work of Moeller (1976), whose findings were based solely on a survey of the physical remains, and who had concluded that the industry was large enough to be a major exporter. It also challenged the work of Jongman, who had reviewed Moeller's findings and, using Moeller's evidence, concluded that Pompeii would have relied on imports (Jongman 1988). Hopkins' study was based on data that had come from her gaining a basic practical knowledge of dyeing then using this to re-survey the original remains in Pompeii. The importance of the inclusion of craft skills within experimental archaeology was demonstrated when Hopkins' results were challenged at the European Textile Forum 2009, when it was shown that if a different technique had been used, that is if the dyeing occurred in batches, the industry's output could have been three times greater than the estimates (Hopkins 2013a; 2013b; 2013c).

Further examination of Hopkins' findings from the craft viewpoint showed the importance of a fuller understanding of practical dyeing. Hopkins had undertaken a new survey of physical remains (Hopkins 2007) in which it was noted that the remaining dyeing kettles had been constructed from lead (Hopkins 2007; Monteix and Pernot unpublished). This finding was noted as an anomaly, but otherwise not investigated. Computer simulation was used to investigate the structural properties of the lead vats, leading to the conclusion that the vessels suffered from 'creep', as shown by kettles Vat 5 and Vat 6 VII xiv 17 (Fig. 8.1), but that this would not have restricted their use. Lead is so infrequently used that the data for the simulation had to be generated during the study (Hopkins 2007; 2008; 2013a). There was no investigation of the vessels from a dyer's viewpoint, and further research showed that apparently such an investigation had never taken place.

At this point it is important to note that when making sweeping assertions about archaeological findings, there needs to be an awareness that further evidence may come to light or existing research may not have reached the desk of the researcher. An example of this is Monaghan's assertion that 'There are no sources from Classical and Hellenistic Greece which are specific about dyeing' (Monaghan 2001) and his use of references in plays to reconstruct the dyeing process is at odds with his citing the existence of *Papyrus Leidensis* and *Papyrus Holmiensis* which he then dismisses as not being Greek. Monaghan cites Balfour-Paul (1998, 124) and Forbes (1956) to support this,

whereas this study cites Lagercrantz who translated these texts into modern German in 1913, citing that they did concern Greek dyeing from Greece. Despite copious research Mongahan appeared to remain unaware of the Lagercrantz translation. These problems are becoming less severe due to communication breakthroughs, such as the advent of the internet and databases of research (after Paardekoooper 2010), but still remain. Hopkins' findings were based on valid science and archaeology, but the understanding of historic dyeing was based on sources available in Britain at the time of the study. Presentation to the international Textile Forum highlighted, challenged and began to correct this issue (Hopkins 2013a; 2013b; 2013c).

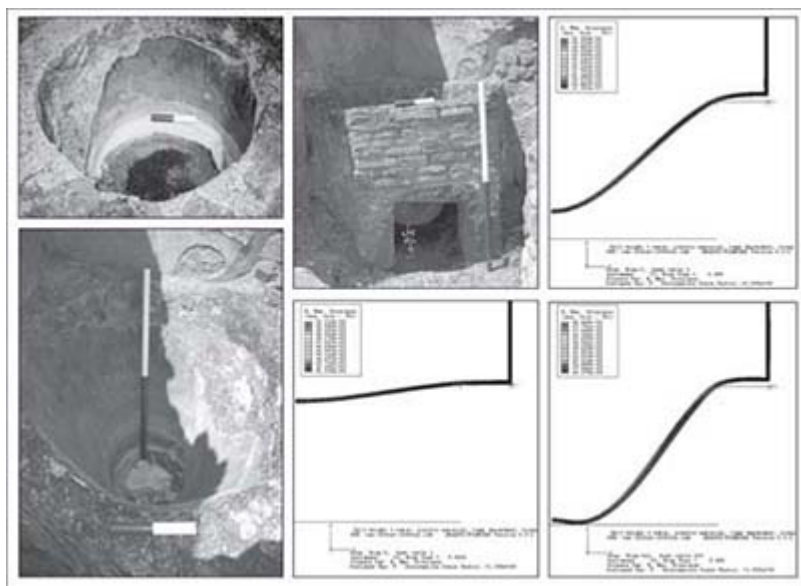


Fig. 8.1. Top left: Photograph of dyeing apparatus 5 in property VII xiv 17 showing creep. Bottom left and top middle: Photographs of dyeing apparatus 6 in property VII xiv 17 showing creep. Bottom middle: Finite Elements Analysis simulation showing cross-section of dyeing kettle after 10 minutes of heating. Top and. bottom right: FEA simulation showing cross-section of dyeing kettle after one dyeing cycle and 160 dyeing cycles

The survey revealed that the kettles, although varying in size between 90 and 900 litres, were of similar geometry. This suggests that their shape may have been chosen to limit structural problems. It may also indicate their use, as the shape is inappropriate for successful fleece dyeing and better suited to dyeing yarn. It is also possible that there were economic or other intangible considerations – the dyers may have been unable to choose the kettles they used. This could be

an area for further research.

Roman dyeing kettles did not have to be constructed from lead: copper and iron were also available. That lead was used was met with disbelief due to its physical properties, such as its instability in heat or under weight (Hopkins 2007; Kania *et al.* 2014). Lead was known to be poisonous (Vitruvius VIII). Logically, as the Roman dyers were running businesses, lead would only have been used if it had an advantage over other materials. It is possible that this advantage may have been intangible, such as material cost or a widespread belief related to cultural, spiritual or other intangible considerations, but the sheer structural difficulties encountered when using lead for these sizeable vats suggest a reason more relevant to dyeing. It required the expertise of a professional dyer to address the question of what the advantage of lead or the disadvantage of other materials could be (Hopkins 2013b). It was speculated that lead could give a chemical advantage (Hopkins 2007). From dyeing experience, it could be confidently stated that copper and iron could not be used to construct a ‘neutral kettle’ to give a pure, unadulterated colour. As there are so many factors that can influence a dyeing outcome, however, specific experiments were necessary to investigate the influence of the metals alone.

Mordanting and dyeing procedure

There are two types of natural dye for textiles: mordant dye and vat dye. When using a vat dye, the material to be dyed is submerged in the dye, which binds to the fibres through an oxidative process when the textile is taken out of the vat. When using a mordant dye, the material to be dyed must first be treated with a solution containing a water-soluble metal salt, the mordant, which then binds to the fibre material. Following this, the textile can then be submerged in the dye-bath and the dye will bind to the mordant and, therefore, the material. The same dye can result in different colours due to the use of a different mordant. This difference is often called nuancing (Fig. 8.2). Copper and iron are known to make the resultant colour darker or ‘sadden’ it, that is make it ‘murky’. Lead is not known to be used as a mordant (cf. mordants listed in Schweppe 1993; see also Ploss 1977). While vat dyes, according to experience, are not very susceptible to changes in the kettle or vat material, mordant dyes can be influenced considerably. Therefore only mordant dyes were used to investigate the effect of different metal materials used as a dyeing kettle.

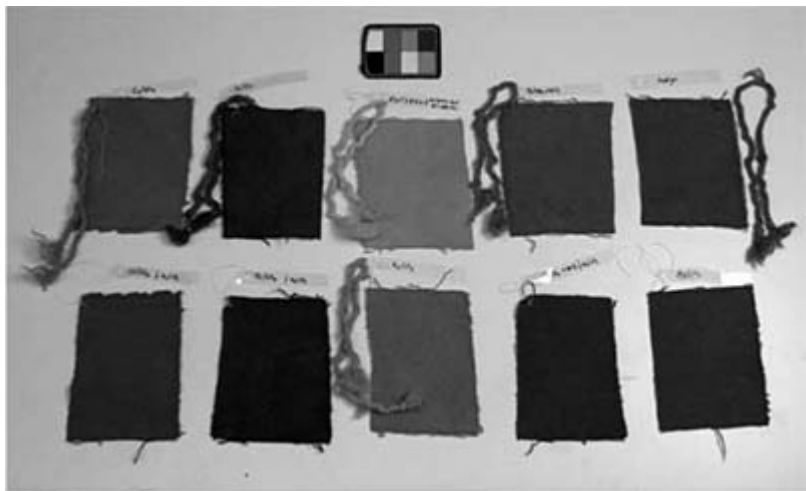


Fig. 8.2. Example of different colour outcomes by using various mordanting agents to nuance wool premordanted with alum and dyed with birch leaf. Colour versions of this and the other photographs can be found on textileforum.org/en/atms-2-images.

Dyes show changes caused by different metals differently to each other. Yellow dyes, due to the light tone value, are most vulnerable to changes, reacting best and most visibly to the factors that may alter a dyeing outcome. Other dyes, such as madder, usually used to dye red, also show sensitivity to water hardness and water quality, temperature and other factors. In combination with different mordants and ageing of the dye plant madder, this may result in colours ranging from salmon pink through a red spectrum to purple or paprika yellow/red and reddish– brown colours. Yellow colour components can be found in most plants, so understanding the nuancing of yellow colours is helpful for the understanding of nuancing in other colours derived from plants as well.

Mordanting procedure

The procedure for mordant dyeing consists of two steps: The material to be dyed is first boiled in water with the mordanting agent, alum ($\text{KAl}(\text{SO}_4)_2$), and left for several hours in the mordanting bath. The material is then rinsed and put into the hot dye bath. The typical concentration of the mordant is 25% of dry wool weight, while concentration of the plant material for the dye bath depends on the plant, harvest quality, whether the plant is dried or fresh, and desired colour depth. The temperature and duration of the dyeing can also vary.

As it was not known whether it was the influence of the metal kettle during the mordanting or during the dyeing process that caused the colour change, metal plates were added to both the mordanting and the dyeing bath. Theoretically, once the fibre has been mordanted, the fibres would become saturated with mordant and should then be insusceptible to further chemical change. After all, it is the mordant, not the fibre, that binds to the dye. However, it was not possible to tell without experiment the stage at which the metal influenced the dyeing – making assumptions and discounting stages could lead to an incorrect understanding. Due to this, the experiments included each stage of mordanting and dyeing.

Wool can be dyed as fleece, yarn or fabric. It is sometimes assumed that if the core of yarn is dyed through that the wool was dyed as fleece (after Wild 1970). This is, however, not necessarily the case, as dyeing may penetrate the core of spun yarn. In the experiment, dyeing took place in the yarn, partly to allow uniform batches, partly because the shape of the dyeing vessels suggests the dyeing of yarn, not fleece. Economically, dyeing yarn is better than dyeing fleece: dyeing requires the use of skilled work as well as expensive and time-consuming processes and materials. When dyeing in the fleece, however, parts of the dyed fleece that would be discarded when processing the fleece for spinning are dyed, thus resulting in expensive waste products.

The dyeing apparatus in Pompeii all appear to have had the ability to be heated. This does not mean that they were necessarily used for hot dyeing. However, the climate and heating through the ambient temperature of the dye works or close proximity to other, heated, apparatus would mean that the dyeing apparatus would have become heated due to its proximity to other dyeing apparatus in an enclosed space. This effect may have been advantageous, possibly shortening the dyeing time required.

First experiments

The first experiments to examine the effect of the type of metal used to construct the mordanting and dyeing kettles in Pompeii were undertaken at the Laboratory for Experimental Archaeology (LEA) in Mayen, a part of the Römisch-Germanisches Zentralmuseum, as part of their inaugural event, the hosting of the European Textile Forum in September 2012. LEA not only has a well-equipped laboratory and conference facilities, but also is located in grounds that meant that it was possible to acquire ingredients used for dyeing, such as fresh birch leaves, and to undertake lengthy experiments that require a

steady monitorable environment over several days. Although birch is a historic dye, it is unknown if fresh birch would have been available in Pompeii or used by the dyers if it was available, but its use in the experiment allowed consistency and comparability in the study.

The dyes chosen for use in the experiment were madder (red) and birch leaf (yellow). Madder was the most commonly used dye in the Roman world, as evidenced by findings at Masada (Sheffer and Granger-Taylor 1994; Koren 1994) and Hadrian's Wall (Taylor 1983) and had been used during the earlier study of the dyeing industry (Hopkins 2007; 2008). This meant that these experiments could be linked back to the earlier study. Linkage is restricted, though, as in true experiments only one factor is changed at a time to allow its influences to be fully understood (Coles 1979; Crumlin-Pedersen 1999). In the case of this series, linkage is limited partly due to different harvests of the dye plants and partly due to slightly different setup. Birch was chosen as it is a historically available yellow dye and yellow dyes allow the subtler changes, that would not be so easily discernable through use of madder, to be detected. Yellow dyes were used by the Romans, but their use provides a reminder to never exclude intangible influences: yellow gowns are depicted in Pompeii, but Pliny states that the dye was reserved for use in bridal gowns. It can therefore be supposed that it might not have been commonly used. The madder used was ordered from a dyers' supplier, the birch leaf used was freshly gathered in the grounds of LEA. Tap water was used throughout, except for cleaning monitoring probes where de-ionised water was used. Although the tap water of Mayen was not from the same source as Roman Pompeii's, this was chosen in preference to other water sources, such as rain water, as the content is known, allowing comparison and the discernment of any affecting factors. This was the same decision made during the original study, undertaken in the UK (Hopkins 2007).

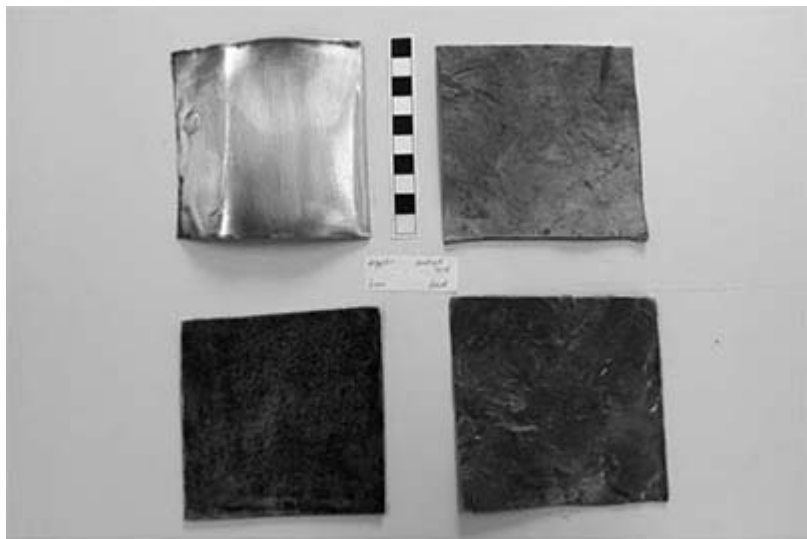


Fig. 8.3. Metal plates to simulate different metal kettle materials, before first use. From top left clockwise: copper, oxidised lead, clean lead, iron

Experiment

Experiment summary

The influence of different kettle materials was evaluated by dyeing of wool yarn, Nm 15/2, c. 11g/ 80 m length each. The wool was mordanted with alum, 25% of yarn weight for each skein as mordant and then dyed with madder, half the dry weight of each skein, or fresh birch leaves, double the dry weight of each skein.

Simulation of different metal kettles was achieved through inserted metal plates, c. 100 mm² each: copper, lead, oxidised lead, iron ([Fig. 8.3](#)). Dyeing and mordanting took place in glass laboratory jars to ensure a neutral environment.

Experiment procedure

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MORDANTING PROCEDURE

Wool skeins of a set weight (10–11 g; [Table 8.1](#)) from an Nm 15/2 yarn were wound. The wool was soaked in cold tap water for several minutes until the fibre was saturated with water; no soap was used. The alum was measured into 1000 ml glass jars according to the calculation (25% of the dry wool weight), 800 ml of cold tap water

was added, and the alum powder stirred until dissolved. pH value was measured, then both the metal plates and the soaked wool skeins were added. A second pH measurement was taken after 10 minutes.

Table 8.1. Weights of samples used

	Reference	Lead oxidised	Lead	Copper	Iron
Madder: wool weight dry before mordanting	11.3	11.1	11.1	10.3	10.3
Alum added	2.8	2.8	2.8	2.6	2.6
Birch: wool weight dry before mordanting	11.0	10.8	10.8	10.7	10.5
Alum added	2.8	2.7	2.7	2.7	2.6



Fig. 8.4. Electric canning pot used as a water bath to ensure even heating of the five sample jars

All heating processes took place in a large electric pot to ensure the same heating curve for all samples (Fig. 8.4). The glass jars were placed in a water bath at room temperature and then heated up. Heating process started at 15:10 h, boiling point was reached at 16:03, and the mordant was kept at a boil for one hour; the mordant was stirred gently as necessary.

During the heating and boiling process, approximately 100 ml evaporated from each of the sample pots.

After boiling for one hour, pH was measured again; the hot mordant liquid and the wool skeins were moved to 800 ml beakers, without the metal plates, to simulate removal into a bucket or different, neutral pot for cooling. The beakers were placed into the hot water bath again to slow down the cooling process, then left to cool overnight.

PREPARATION OF MADDER DYEING

The madder dye bath was prepared by measuring out the individual amounts of madder powder into the glass jars that were previously rinsed out with cold tap water. A concentration of 50% dry wool weight was chosen since it is easier to see colour differences in lighter shades of colour than in darker shades. 800 ml of tap water were added to each of the jars and stirred, then the madder was left to soak overnight at room temperature. The metal plates were not added yet to simulate soaking the madder in neutral pots or buckets.

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pH of the cooled-down mordant baths was taken; the madder was stirred up again and pH measured. The metal plates were added to the madder dye pots and after 10 minutes, the pH was taken again. Samples for later analysis were taken from each of the mordant baths, then the rest of the bath was discarded and each skein rinsed individually under running, cold tap water for 60 seconds before immersion of the skein into the dye bath. The metal plates were cleaned with water; superficial residues and oxidation were removed with very fine sandpaper from the iron, copper and unoxidised lead plates and rinsed off. The oxidised lead plate was rinsed only.

The cleaned metal plates were inserted into the dyeing vessels. The madder dye jars were then heated in the water bath until the boiling point and boiled at one hour. Heating up to the point of boiling took c. 50 minutes again. The dye was gently stirred as necessary (seven times altogether). After the start of heating up, the madder included a grey tinge in the iron and lead samples, no grey tinge in the reference and in the copper pots during the first 15 minutes of heating. Distinct differences were observable in the tinge of the colour moving into the fibres.

pH was measured about half an hour into heating up and again right after the hour of boiling time was finished. After one hour cooling down in the water bath, the dye liquid had cooled to approximately 50°C; pH was measured again and then the skeins were rinsed until the water ran clear, a sample of the dye liquid was taken for later analysis and the rest of the dye was discarded. The skeins were hung up to dry. Very distinct differences in the colour of the dyed skeins could be observed. The mordanting and dyeing liquids showed only very slight, if any, differences in their colour ([Fig. 8.5](#)).



Fig. 8.5. Madder-dyed skeins, mordanting and dyeing liquids. From left to right: iron, clean lead, oxidised lead, reference, copper



Fig. 8.6. Dye liquid preparation with fresh birch leaf

For a second test run with yellow colour, a new mordanting bath was prepared just like the day before; start of heating was 15:00 h. At about the same time, fresh cut and shredded birch leaves (200% of

dry wool weight) were added to 800 ml glass jars together with 800 ml of tap water and heated up to the boiling point on heating plates, then boiled for one hour with automatic magnetic stirrers to extract the pigment from the leaves (Fig. 8.6). The leaves were left in the jars to cool off overnight.

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pH measurement of the cooled mordant was taken as well as a pH measurement of the birch leaf dye liquid after straining it with coffee filters. The dye liquid was topped up to 800 ml per jar with cold tap water, and the metal plates were inserted into the jars. Skeins were rinsed under cold tap water as before; pH was measured 10 minutes after inserting the metal plates into the dye bath, then the skeins were put in.

It was noted that since the dye liquid looked quite different from batch to batch (Fig. 8.7), it might be helpful for further experiments to cook up all the dye liquid in one single batch, strain it and then distribute it according to the dry wool weights to the individual jars. The dye pots were put into the water bath and heated up to the point of boiling, again stirred as necessary (less often than for the madder bath). While heating, differences in the skein colour already became visible; the dye liquids also showed different discolourations (Fig. 8.8).

Results were very clear: the clearest, brightest yellow was the one dyed with the oxidised lead piece in the jar, the reference was slightly more orange, and the other three samples were much less yellow. This leads to the conclusion that a lead dyeing pot with an oxide layer on the surface would have been a suitable pot to dye yellow (A colour photograph of the skeins can be seen on the cover of this book).

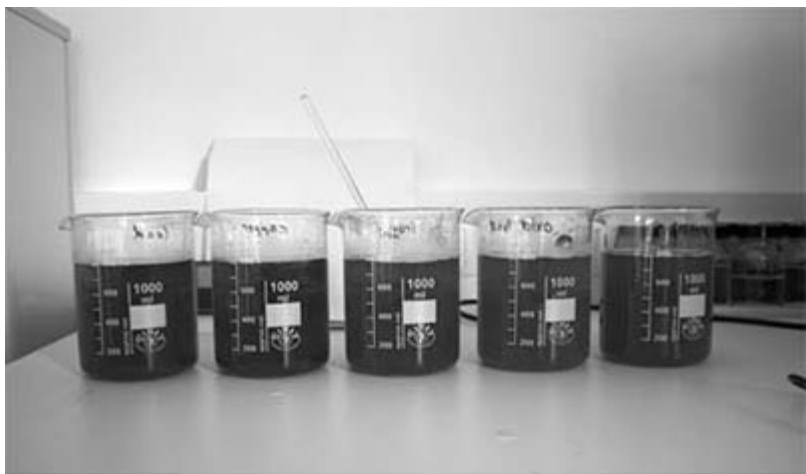


Fig. 8.7. Different hues of the five batches of birch leaf dye liquid, before inserting the metal plates



Fig. 8.8. Birch-dyed skeins and dyeing liquids. From left to right: iron, copper, clean lead, oxidised lead, reference

Throughout the mordanting and dyeing the pH of the liquid was recorded (Tables 8.2 and 8.3). This was to monitor changes undertaken during the dyeing process, in particular to identify if one beaker was showing greater signs of change in water chemistry content than the others. It was understood that it was possible that pH alone may not detect this.

*Table 8.2. pH recorded during dyeing with madder. Temperature differences in the measurements after boiling are due to cooling off of liquid while measuring; measurement row marked * was the only row not measured in the sequence. Tap water: 7.19 pH at 19.6°C*

	Reference	Lead oxidised	Lead	Copper	Iron
pH with alum added	4.18 pH 19.7°C	4.16 pH 19.5°C	4.18 pH 19.5°C	4.18 pH 19.5°C	4.18 pH 19.6°C
pH before heating, wool and metal plates added	4.21 pH 20.2°C	4.18 pH 19.7°C	4.18 pH 19.7°C	4.19 pH 19.9°C	4.19 pH 20.0°C
pH after boiling*	3.35 pH 84.7°C	3.37 pH 80.0°C	3.34 pH 78.7°C	3.36 pH 81.4°C	3.67 pH 77.8°C
pH after cooling	4.04 pH 23.2°C	4.05 pH 23.0°C	4.05 pH 23.0°C	4.06 pH 23.0°C	4.20 pH 22.9°C
Madder weight	5.7 g	5.6 g	5.6 g	5.2 g	5.2 g
pH of madder before adding metal	7.24 pH 21.3°C	7.19 pH 21.3°C	7.14 pH 21.2°C	7.06 pH 21.5°C	7.17 pH 21.4°C
pH of madder after adding metal	7.23 pH 21.6°C	7.18 pH 21.2°C	7.12 pH 21.3°C	7.12 pH 21.3°C	7.17 pH 21.3°C
pH of madder while heating	6.45 pH 63.0°C	6.35 pH 65.8°C	6.35 pH 66.5°C	6.45 pH 67.7°C	6.40 pH 69.0°C
pH of madder pots after boiling	6.40 pH 80.9°C	6.32 pH 80.7°C	6.33 pH 82.7°C	6.44 pH 80.6°C	6.55 pH 78.2°C
pH of madder pots after 1 hour of cooling	6.71 pH 51.3°C	6.58 pH 50.4°C	6.55 pH 51.3°C	6.66 pH 50.6°C	6.78 pH 49.3°C

Table 8.3. pH recorded during dyeing with birch

	Reference	Lead oxidised	Lead	Copper	Iron
pH before heating	4.27 pH 19.4°C	4.23 pH 19.6°C	4.27 pH 19.5°C	4.25 pH 19.3°C	4.28 pH 19.4°C
pH before heating, wool and metal plates added	4.25 pH 20.0°C	4.25 pH 20.0°C	4.26 pH 19.8°C	4.25 pH 19.6°C	4.25 pH 19.7°C
pH while heating	3.56 pH 19.4°C	3.55 pH 19.6°C	3.54 pH 53.5°C	3.53 pH 54.2°C	3.54 pH 54.7°C
pH after boiling	3.30 pH 82.6°C	3.37 pH 82.6°C	3.35 pH 80.0°C	3.34 pH 80.3°C	3.61 pH 79.6°C
pH after cooling	4.20 pH 21.4°C	4.20 pH 21.3°C	4.20 pH 21.3°C	4.18 pH 21.4°C	4.30 pH 21.3°C
Birch leaf weight	22.0 g	21.6 g	21.6 g	21.4 g	21.0 g
pH of birch before adding metal	7.00 pH 21.4°C	7.11 pH 21.5°C	6.85 pH 21.7°C	6.79 pH 22.3°C	7.10 pH 22.1°C
pH of birch after adding metal	7.01 pH 20.7°C	7.07 pH 20.7°C	6.99 pH 20.7°C	6.97 pH 20.9°C	7.08 pH 21.0°C
pH of birch while heating	5.98 pH 67.7°C	5.90 pH 69.2°C	5.83 pH 70.7°C	5.82 pH 71.4°C	5.89 pH 72.1°C
pH of birch pots after boiling	5.45 pH 78.2°C	5.47 pH 77.2°C	5.35 pH 74.8°C	5.36 pH 77.5°C	5.69 pH 75.2°C
pH of birch pots after 1 hour of cooling	5.53 pH 48.3°C	5.55 pH 46.5°C	5.41 pH 46.1°C	5.41 pH 46.1°C	5.72 pH 46.3°C

Samples were taken to allow analysis of the dye liquor to see the quantity of metal that had dissolved during dyeing. Unfortunately, these decayed before they could be analysed.

Conclusion

This experiment demonstrated that not only the mordant played an

influence, but the material the kettle was constructed from does too. It was expected that iron and copper would alter the colour, in particular that iron would cause a greenish colour. The effect of lead, in particular the oxidised lead, in keeping the brightness of the colour in a similar extent as the neutral glass beaker was unexpected –it was suspected by the experimenters that it would make a positive contribution, but the extent of this was surprising. The lead can therefore be declared as a historically available ‘neutral vessel’. It is possible that ceramic vessels or vessels lined with opus signinum, comprising ceramic fragments mixed with mortar and used to line receptacles to contain liquids, could have been used, which could have been as inert. These would have been more difficult to clean, but their use could be further investigated. As historic dyers did not have access to the inert vessels that may be used today, it further demonstrates their skill in including the kettle material as a factor when planning the outcome of their dyeing. The vibrant colours and nuances gained through mordants could also be further varied through the use of different kettles or metal additions, giving an even more expansive palette. This also shows the magnitude of the enormous skills and knowledge required in every aspect of choosing materials and methods in the dyers’ art.

This finding reaches further than the immediate dyeing outcome. The choice of lead looks reckless to modern eyes, but is logical to a historic dyer. It demonstrates the need to properly understand an artefact before making conclusions about its purpose, to prevent modern imposition of ideas leading to false understanding that become perpetuated as facts.

Further work

The results of this experiment posed further questions. It remains unknown if the inclusion of metals in the water would affect the fastness of the dye to light or washing. But most immediately, though it was established that the dyeing outcome was affected by the kettle material, it was not clear whether this occurred during the mordanting, the dyeing, or during both processes. It was concluded that further experiments were required to explore what was happening.

Return to LEA, July 2013

The experiment above, inspired by Hopkins’ thesis about the dye workshops of Pompeii and undertaken in September 2012, clearly

showed that lead kettles could be seen as the historical neutral kettles (Kania *et al.* 2014). The experiment also showed that the influence of the metals added into the neutral glass vessels –clean lead, lead with an oxide layer on the surface, copper and iron –was considerable: both the reference sample and the sample dyed with the oxidised lead plate were a clear yellow, while the clean lead and copper addition resulted in a darker, more orange colour; the added iron turned the yellow dye into a solidly green colour. However, it remained unclear whether the main influence took part during the mordanting process, the dyeing process, or if the influence of the metals was coming equally from both parts. To shed some more light on this issue, a dyeing experiment addendum was designed and undertaken in July 2013.

The experiment to investigate this question took place again at the Labor für Experimentelle Archäologie (LEA) in Mayen, a satellite of the Römisch-Germanisches Zentralmuseum in Mainz. The required mordanting and dyeing procedures, with a total runtime of c. 17.5 hours, were carried out over the course of two days.

The aim of the experiment was to see whether there was any difference in outcome of the colours when a metal kettle influences only the mordanting (subset I) or only the dyeing process (subset II). The mordanting, both in neutral vessels and in vessels with added metal plates took place during the first day. On the following day, the dyeing process was carried out. All samples were processed in laboratory glass jars, heated on heating plates. Tap water was used for dyeing as it was of a known mineral content, and tap water from the same location was used for the mordanting and dyeing of the original experiment. Distilled water was used for cleaning all measuring equipment.

Before both the mordanting and the dyeing procedure, the copper, iron, and lead plates were cleaned under running tap water using fine sandpaper; the oxidised lead was cleaned by rinsing with tap water to preserve the oxide layer.

Choice of materials

For the addendum to the first experiment, fresh birch leaf was chosen as the dyestuff, omitting madder as a second dye since the colour differences were much more visible in the birch dye run compared to the madder dye run. For the addendum, wool and alum from the same supplier were used, as well as the metal plates from the first experiment run. The use of birch in the September 2012 and July 2013 allowed a comparable continuation in the experiment (after Coles 1979; Crumlin-Pedersen 1999). The dyeing material was again

fresh birch leaf, harvested in the same region, if at a different time of year, and the actual experiment was carried out in the same place as the first one. As there were only four heating plates available, no reference sample was dyed this time. This proved to be a poor choice, as it very much limits the comparability between the original experiment and the addendum.

In contrast to the first experiment, the dye liquid was prepared in one large batch, which was then split into equal parts and topped up with tap water. As the weight differences between the individual skeins was very small, there was considered to be less difference in colour outcome this way than if individual batches of dye were prepared for each of the skeins, or several smaller batches. This may be regarded as a change to the experiment, but as it does not materially or chemically change the methodology. Instead, it does allow better accuracy and comparison, thus being beneficial to the experiment as a whole.

Experiment run

Keeping as closely as possible to the procedure of the first experiment, identical skeins of wool were premordanted with alum in an inert glass vessel. The alum weight was 25% of the wool weight. Each vessel for subset I contained a piece of metal of about 100 mm² to represent the dyeing apparatus consisting of different materials: copper, iron, lead and lead with a superficial oxide layer (see [Fig. 8.2](#)); the skeins for subset II were mordanted and dyed without metal addition. The wool was boiled in the containers for an hour, then left to stand overnight.

For the dye liquid, fresh leaves were harvested, cut and soaked in 2400 ml of tap water for 3.5 hours. They were then heated with continuous stirring and boiled for one hour, then left to cool in the liquid. The dye liquid was stirred up, then filtered off the following day using a normal coffee filter, c. 16 hours later.

The strained dye liquid was parcelled out into equal amounts for the eight dyeing pots, then each of the pots was topped up with tap water to 800 ml of liquid. The mordanted skeins were taken out of the liquid and rinsed individually under tap water for 60 seconds. The skeins were then immersed into the dye bath and gently moved approximately every 10–15 minutes. All dye baths were placed on individual heating plates, heated to the point of boiling, then boiled for 1 hour. The pH of the samples was measured while heating, after boiling and after cooling for one hour both during mordanting and during dyeing.

The dyed skeins were removed after the one hour of cooling and again rinsed individually under cold tap water until the water ran clear. Samples of the liquids used for mordanting and for dyeing were taken to allow for testing of the dye liquids.

Experiment results

The pH of the dyeing liquid was recorded throughout in order to indicate chemical changes that may be occurring and the point at which they happened (see [Tables 8.4](#) and [8.5](#)). It was recognised that pH alone may not highlight the changes, but it can be used as a simple indicator.

For the wool samples processed with copper and iron, there is a distinct influence of the metal plate on the resulting colour, and in both cases, the influence is stronger where the metal was added to the dye liquid than to the mordanting liquid. This is especially obvious for the sample with iron. Iron can also be used as a mordant itself, and it is known to result in very strong colour modification. For yellow dyes, iron as a mordant turns the colour to a green shade. The sample processed with iron in the mordant is a light green colour, while the sample with iron in the dye turned out a darker green.

The samples dyed with the clean lead plate only show a very slight difference, with the subset I sample a clear yellow and the subset II sample a clear yellow with a very light reddish tinge. There is no discernible colour difference between the subset I and subset II samples done with the oxidised lead plate; there is also no discernible colour difference between these and the sample processed with clean lead in the mordanting liquid. This further points toward the lead kettle as the neutral vessel for dyeing.

Unfortunately, the lack of a reference sample both mordanted and dyed in a neutral vessel means that it is not possible to do a reliable comparison between the samples from the original experiment and this addendum. Differences in shade may either be due to the influence of the metal, but also to differences in concentration and chemical composition of the dyeing liquid itself, since the birch leaves were harvested in different years and during different times of the year. Furthermore, as the dye liquid batches for the original experiment were produced individually, there may have been differences from batch to batch that influenced the colour outcome independently from the influences of the metals.

Supposing that the oxidised lead has no appreciable influence on the outcome of a dyeing process, whether in the mordanting or the dyeing procedure or both, the original experiment in 2012 shows a

more reddish tinge throughout most of the samples. The 2012 reference, dyed and mordanted in a neutral vessel, also shows a reddish tinge pointing towards more red chemicals in the birch leaf in that year, possibly due to the harvesting in September. (A photograph of the dyeing outcome may be seen on the cover of this book).

Is ‘third time the charm’?

As the original experiment and the addendum could not be fully linked, due to lack of a reference sample in the addendum, the experiment plus the addendum were repeated at the European Textile Forum in 2016. Another reason for the repetition of the experiment was the difference in hue of the copper-influenced samples, with the ones from the first experiment run showing a distinctly reddish colour that was missing in the samples from the addendum.

Table 8.4. Addendum 2013, changes in pH, subset I: mordanting with metal plates (reference value from original experiment)

	Reference	Lead oxidised	Lead	Copper	Iron
Wool weight dry before mordanting	11.0 g	10.8 g	10.81 g	10.82 g	10.9 g
Alum added	2.8 g	2.7 g	2.7 g	2.7 g	2.7
pH with alum added	4.27 pH 19.4°C	4.03 pH 25.6°C	4.04 pH 25.0°C	4.06 pH 24.5°C	4.06 pH 24.2°C
pH after adding metal and wool		3.95 pH 25.7°C	3.97 pH 25.4°C	3.98 pH 25.0°C	4.03 pH 24.6°C
pH while heating, wool and metal plates added	4.25 pH 20.0°C	3.70 pH 40.4°C	3.72 pH 40.0°C	3.72 pH 40.0°C	3.71 pH 41.4°C
pH after boiling*	3.30 pH 82.6°C	3.19 pH 85.5°C	3.20 pH 83.7°C	3.20 pH 80.5°C	3.60 pH 77.7°C
pH after cooling	4.20 pH 21.4°C	4.01 pH 25.2°C	4.02 pH 25.0°C	4.03 pH 24.9°C	4.21 pH 24.9°C
Birch leaf weight	22.0 g	21.6 g	21.6 g	21.6 g	21.8 g
pH of dye liquid while heating		6.60 pH 34.8°C	6.56 pH 38.2°C	6.61 pH 36.6°C	6.58 pH 38.2°C
pH of dye liquid after boiling	5.45 pH 78.2°C	5.50 pH 83.1°C	5.54 pH 78.5°C	5.56 pH 76.8°C	5.69 pH 73.8°C
pH of dye liquid after one hour of cooling	5.53 pH 48.3°C	5.51 pH 41.8°C	5.56 pH 41.7°C	5.60 pH 41.7°C	5.76 pH 40.2°C

Table 8.5. Addendum 2013, changes in pH, subset II: dyeing with metal plates (reference value from original experiment)

	Reference	Lead oxidised	Lead	Copper	Iron
Wool weight dry before mordanting	11.0 g	10.63 g	10.64 g	10.73 g	10.73 g
Alum added	2.8 g	2.7 g	2.7 g	2.7 g	2.7
pH before heating, after adding wool		4.07 pH 25.4°C	4.07 pH 26.0°C	4.03 pH 26.9°C	4.09 pH 25.4°C
pH while heating, wool added	4.25 pH 20.0°C	3.37 pH 66.1°C	3.40 pH 65.8°C	3.37 pH 68.4°C	3.37 pH 68.0°C
pH after boiling*	3.30 pH 82.6°C	3.23 pH 94.2°C	3.22 pH 90.0°C	3.20 pH 87.6°C	3.24 pH 84.8°C
pH after cooling	4.20 pH 21.4°C	4.01 pH 25.3°C	4.02 pH 25.0°C	4.02 pH 24.9°C	4.01 pH 25.1°C
Birch leaf weight	22.0 g	21.3 g	21.3 g	21.5 g	21.5 g
pH of dye liquid before adding metal and wool		6.76 pH 27.2°C	6.84 pH 26.6°C	6.86 pH 26.3°C	6.88 pH 27.1°C
pH of dye liquid after adding metal and wool		6.76 pH 27.3°C	6.79 pH 26.8°C	6.83 pH 26.3°C	6.88 pH 27.1°C
pH of dye liquid after boiling	5.45 pH 78.2°C	5.41 pH 85.7°C	5.47 pH 83.7°C	5.43 pH 81.2°C	5.63 pH 79.0 °C
pH of dye liquid after 1 hour of cooling	5.53 pH 48.3°C	5.47 pH 42.1°C	5.54 pH 42.8°C	5.53 pH 42.7°C	5.62 pH 41.9°C

A total of 14 skeins, weighing 5.08–5.11 g, were prepared. These were first mordanted, partly with and partly without metal addition, and then dyed, again partly with and partly without metal addition. The metal plates were prepared and used like in the previous experiments. As the conference took place in November, fresh birch leaf for the dye liquid was not available; dried birch leaf was used instead, at 100% of dry wool weight. The dye liquid was prepared in one batch and then split up for the dyeing in the glass jars. The other experiment parameters –length of mordanting and dyeing time, mordant concentration etcetera –all remained as in the original experiment and the addendum.

The result were three groups of samples: one mordanted with a metal plate in the jar and dyed with a metal plate in the jar; one only mordanted with a metal plate in the jar and dyed in a neutral vessel; and one mordanted in a neutral vessel and dyed with a metal plate in the jar. Two reference skeins, mordanted and dyed in a neutral vessel, were also made.

The results were similar to those of the first experiment regarding the differences between the iron ‘kettle’ and the reference. As in the original experiment and in the addendum, the added iron plate led to a greenish colour of the dyed wool. Differences between metal addition in the mordant only, in the dyebath only and in both were best visible in the sample with the iron plate present; differences for the copper and lead plates were less pronounced (Fig. 8.9).



Fig. 8.9. Experiment run 2016, comparison between the samples. From left to right: Subset A, metal plate both in mordanting and dyeing bath; Subset B, metal present in mordanting bath only; Subset C, metal present in dyeing bath only. Sequence in each subset from top to bottom: reference sample/undyed sample, oxidised lead, clean lead, copper, iron

In comparison to the original experiment, the samples dyed with the clean lead plate and the copper plate present were much less reddish in tinge and did, in fact, not differ very much from the reference. The copper samples show a slightly less vibrant, brownish-tinged hue in the 2013 and 2016 experiments. The reddish tinge is thus probably due to a higher quantity of a birch leaf component that reacts more strongly with copper in the 2012 birch leaf harvest than in the other ones, maybe linked to the time of year when harvesting the leaves.

Comparison between the original experiment, the addendum and the full experiment in 2016 shows that there is indeed a considerable difference between the influence of the kettle material in combination with the mordant, the dye, or both (Fig. 8.10). The kettle material leads to a greater change in colour when in contact with the dye bath and has much less effect when present in the mordanting. With a metal plate in the dyeing bath only, the colour change is almost as strong and deep as the change caused by the metal plate present during both mordanting and dyeing. Differences between the copper, lead, oxidised lead ‘kettles’ and the neutral glass jars further depend on the specific variations in the dye components, which will vary according to the individual conditions such as weather, plant subspecies, climate, time of year and many other factors.



Fig. 8.10. Comparison between samples from all experiment runs

Top row from left to right: Experiment 2012, madder dyeing, top to bottom: undyed sample, reference, oxidised lead, clean lead, copper, iron; experiment 2012, birch dyeing, top to bottom: undyed sample, reference, oxidised lead, clean lead, copper, iron; experiment addendum 2013, top to bottom: copper in mordant, copper in dye, iron in mordant, iron in dye, clean lead in mordant, clean lead in dye, oxidised lead in mordant, oxidised lead in dye. Bottom row from left to right: experiment 2016, subset A, metal plate both in mordanting and dyeing bath; Subset B, metal present in mordanting bath only; Subset C, metal present in dyeing bath only. Sequence in each subset from top to bottom: reference sample/undyed sample, oxidised lead, clean lead, copper, iron.

Summary and further questions

The effect of metals, especially of iron and copper, on dyeing with alum mordant and plant dyes has long been known and used to modify colours. Whether this influence is mainly taking place during the mordanting or dyeing, and whether there are distinct differences between samples with a metal influence in just the mordant, just the dye, or both, has hitherto not been in the focus of research.

The experiment done in 2013 is both confirming that the lead vessel, especially if coated with an oxide layer, is a neutral vessel suitable for dyeing a bright yellow, and pointing towards distinct differences in the influence of metals on the process depending on their presence in the mordanting procedure or the dyeing procedure.

The outcome indicates further chemical processes occurring that

warrant further research. The dye liquor used was acidic and it may be expected that this would have caused greater dissolution of the metals present, but the acidity between the mordanting samples and dyed samples remains approximately the same. This therefore does not explain why the metal placed in the dyeing vessels had a greater effect on the colour outcome than the metal placed in the mordanting vessels. All three metals – copper, iron and lead – affected their samples more during dyeing than mordanting. Possibly this is due to having more metal ions present in the mordanting bath through the mordant.

As expected, the effects differed depending on the metal. Iron reliably transformed the yellow into a solidly green shade, although this had a lesser effect in the mordant than in the dye vat. There is no readily discernible difference between the yellow dyed with copper in the mordant and the samples mordanted and dyed with lead, while the 2012 sample dyed with copper present is slightly darkened and has a reddish tinge.

The mordanting and dyeing samples containing the lead square with the oxidised surface both from the original experiment, from the addendum and from the 2016 experiment were a clear yellow colour. The sample mordanted and dyed with the un-oxidised lead square in the first experiment shows a reddish tinge which was not present in the samples mordanted or dyed in the second experiment; the third experiment run, which also lacks the reddish tinge, suggests that this is due to differences in the plants used for dyeing and might have been an exceptional phenomenon.

All three experiment runs, however, show that lead, especially with an oxidised surface, constitutes a ‘neutral kettle’ which allows the dyer to produce a bright yellow. This also highlights further the skills of the dyers in allowing for the nuances caused by the vessel and the dye stuff.

In retrospect, omitting the reference sample mordanted and dyed in a neutral pot for the experiment addendum 2013 was a bad decision, since it severely limited the possibility to compare the addendum samples to the samples from the original experiment. The dye concentration and exact tone of the birch leaves remains unknown without the reference sample, and since there is a significant difference in colour depending on whether the metal was added to the mordanting bath or the dye bath, it is not possible to compare the outcome from the two experiments.

However, this led to the third experiment run to validate the findings from the original run and the addendum and to compare

them. This, in turn, shows that the original run with its reddish tinge present may have been an odd result. In our case, this was a lucky streak, as it encouraged further investigation and also shows that while copper may allow a dyer to achieve a true yellow under some circumstances and with some dye liquids, it is by no means guaranteed that this will be the case. The triple experiment run also emphasises one of the basic challenges of experimental archaeology: working with natural materials means having to take variations into account that are very hard or impossible to measure and that cannot be gauged beforehand. For any experiment using natural materials in a key function, for instance for dyeing, it would thus be very desirable to have not only one run of the experiment, but at least three, using similar material from the same plant or animal species, but not from the same batch. This allows for an evaluation of how strongly the effects of the material are in comparison to other effects tested in the experiment.

While an archaeological experiment, per definition, is designed to be as repeatable as possible, it is very uncommon for them to actually be repeated. The dyeing experiment clearly shows that a repetition of an experiment is no waste of time and effort, but a very good idea, especially when natural materials are involved.

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Chapter 9

The supply of water to the dyeing workshops of Pompeii

Heather Hopkins

The city of Pompeii was destroyed and its remains preserved during the eruption of Mount Vesuvius in AD 79. The dyeing apparatus in Pompeii have survived *in situ* allowing the reconstruction of an industry in the city it supplied. Moeller had surveyed the dyeing apparatus of Pompeii and concluded that the industry was large enough to export (Moeller 1976, 29-56, 105-111). Jongman, using Moeller's data, concluded that Pompeii's dyeing industry had been small enough to depend on imports (Jongman 1988, 157-158, 184-186). These earlier studies relied on a theoretical understanding applied to the superficial measurement of the apparatus remains. The only way to discover the maximum capacity of production was to re-survey remains, then construct and use replicas of the relevant parts of the industrial equipment. It was concluded that the dyeing industry was small, only capable of producing enough dyed material to provide each of its inhabitants with the equivalent of 8 kg of dyed fleece annually (Hopkins 2007, 193-199). This study moved from a Classical question through Experimental Archaeology, into the principles of Engineering, withstanding academic criticism within each field, resulting in a more robust and solid foundation for further exploration. Now it is possible to examine the process as a whole and the factors that would have affected or limited it.

The dyeing process is part of a larger textile manufacturing process (Fig. 9.1). It can be described using inputs, a process and outputs. (Fig. 9.2) Inputs include the raw materials that become the finished product and in dyeing include the dye, the material to be dyed and, if necessary, the mordant. Textiles can be dyed at different stages during manufacture, so the material may be fleece, yarn or cloth. These

inputs are classed as 'consumables' – items required for manufacture that are consumed during the process. Other consumables in a process are the material resources that do not become part of the finished product but allow the process to occur. In dyeing, these are the fuel that heats the apparatus, the movement of the dyer and the water that the dye is suspended or dissolved in. A lack of a consumable limits the output of the process: to gauge a maximum production capacity, the availability of consumables must be understood. The source, quality, transport costs and storage of consumables would have affected their use, supply and cost. The outputs of the dyeing industry were the dyed material and the waste products: the used dye liquor, any spoiled material that could not be re-used, exhaust gases and heat from the apparatus. Technically, accumulation of an output could limit manufacturing, but absence of an input has a greater effect as it stops the process altogether.

It was assumed in this study that the material used was wool and the dye used was madder as these were the most commonly used materials in the Roman world (Hopkins, 2007, 23-25, after Taylor 1983; Sheffer and Granger-Taylor 1994, Bender Jorgenson and Mannering 2001). Madder is a mordant dye, requiring a metal salt (a 'mordant') to bind the dye to the cloth. Alum was a common mordant used for madder throughout the Roman world (Hopkins 2007, 29 after Sheffer and Granger-Taylor 1994). To pre-mordant with alum and to dye with madder requires these chemicals to be dissolved or suspended in water and then heated. Other dyes, such as woad, do not require premordanting and do not benefit from heating. Not all textiles were dyed and some were re-dyed. The difference that these factors would make to the overall quantities of consumables used shall be discussed below.

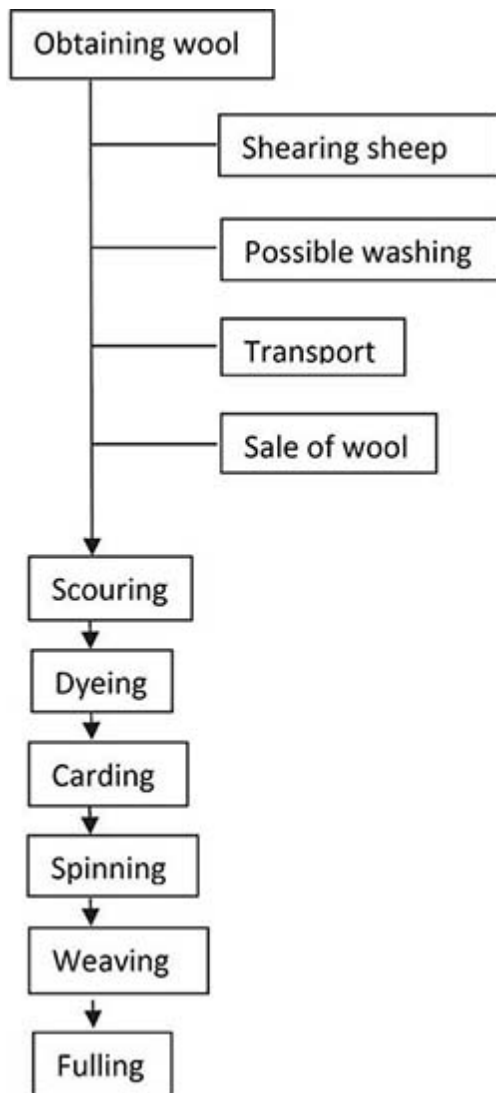


Fig. 9.1. The dyeing process is part of a larger textile manufacturing process. The stages of textile manufacture (after Moeller 1976; Frayn 1984)

The recipe used in the reconstruction was an amalgamation of several preindustrial recipes. The closest complete recipe was Storey's (1978, 66-67). Storey states that hard water is needed for dyeing with madder. Hard water is only required for certain recipes. 'It is best to use soft water for dyeing. Only a few dyeing recipes prescribe the use of hard water, e.g. those for dyeing madder on iron mordant to obtain violet shades' (Schweppe 1986). To harden water, chalk may be added (Storey 1978, 67; Schweppe 1986). This means hypothetically that the

supply of soft water is beneficial as this can be hardened more easily than hard water softened for other recipes.

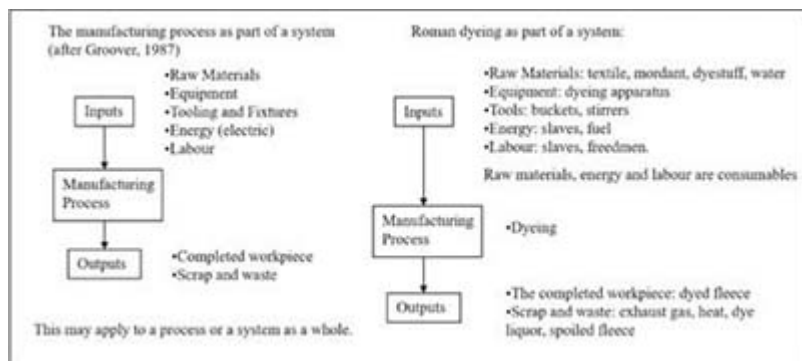


Fig. 9.2. Dyeing process as part of a manufacturing system. Scrap and waste are only determined after the final process as it is possible that the item could be ruined during the final process

Water content

It is important to understand the content of the water used in dyeing, as this affects the dyeing outcome. During Pompeii's life its water source varied, the water content changing with it. The affect of water content on dyeing outcome was known before the modern era (for example, Rosetti 1548). Additives change the pH and chemical composition, which may result in a dye not remaining 'fast' (washing out of the cloth or fading in light) or turning an unexpected colour. This would have had economic implications to the dyer and owner of the material. Understanding the dyers' water source and supply allows insight into how the water content may affect the dyers' result.

Pompeii was constructed on 'a tongue of lava reaching down to the coast' (Arthur, 1986, 29). The volcanic rock was known of and used locally (Peacock 1989, 206). Locally derived water should be soft and Pompeii ideally placed for dyeing. But Pompeii's water was not locally derived, coming instead via an aqueduct from Campania (Hodge 1992, 282; De Haan 1997). The aqueduct and fountains were Augustan in date, built to provide better quality drinking water and to imitate the improvements in Rome (Richardson 1988, 51; Laurence 1994, 44;). The aqueduct superseded the wells and cisterns as the source of water in Pompeii prior to the AD 79 eruption (Hodge 1992, 58; Laurence 1994, 44). This water flowed over sedimentary rock, possibly contained a higher mineral content and so was hard water

(after Frayn 1984, 11-27). The dyers were thus supplied with hard water, which coincidentally was suited for dyeing with madder.

Demonstrating that Pompeii had hard and lead-free water goes hand-in-hand. This is a pertinent assertion as the dyeing kettles and some water pipes were constructed from lead. Hard water would have decreased the lead that could leach into the water (see below). As lead can act as a mordant, lead in the water may decrease the quantity of mordant required. It should be noted, though, that the colour may not be any more fast (stable).

Was there lead in Pompeii's water?

Vitruvius wrote the *Ten Books of Architecture* (*De Architectura*) contemporaneously to Pompeii (Vitruvius). In this Vitruvius showed an awareness of materials. Modern knowledge and examples have led to the presumption that there was a constant danger of lead poisoning in Pompeii as water pipes were made of earthenware and lead (Hodge 1981, 488-489). Lead pipes cannot be used to supply soft drinking water in a system with storage: to be safe the water must be hard or constantly flowing. Vitruvius only mentioned (soft) spring water in his 'tests of good water', described a system of continuously flowing water and advised against using lead pipes (book viii, chap. IV 1; chap. vi 4-5, 10-11). The survey undertaken in 2002 confirmed the use of lead and clay pipes (Fig. 9.3). Vitruvius did not write after seeing the effects of lead pipes: he recorded the effects of accumulative lead poisoning in lead workers, citing it as evidence of the dangers of lead use. This shows that lead poisoning was known of and recognised. Vitruvius did not record any other lead poisoning in society, as a whole or within a profession, including dyers.



Fig. 9.3. Waterpipes in Pompeii: left) lead; right) Clay (photo: author, 2002)

Pompeii's water was hard: modern records and photographs show calcium deposits and silting on the aqueducts leading into Pompeii. Hodge cites Forbes saying 'Roman aqueducts suffered from serious deposits and incrustations of carbonate of lime and had to be cleaned out frequently' (Forbes 1955 cited in Hodge 1981, 488). Calcium carbonate coats the pipes, absorbs lead and prevents contact of the pipe with water, an engineering principle still used into the modern era. Lead poisoning did not occur as contamination was low or non-existent.

It could be argued that using hard water and lead together in Pompeii was serendipity, but constructing a city's water supply on the off-chance it might not poison the inhabitants would be an expensive risk to undertake. The Romans were pragmatic engineers: the system was reliable and safe. Using hard water was one feature that meant using lead was safe. Another was the system's design.

Pompeii's aqueduct was supplied by springs at Serino. At Sarno it divided, a branch coming to Pompeii (Hodge 1992, 282). This meant the water was constantly flowing: it could not be switched off without backing up and flooding the town. The fountains overflowed, washing the streets. While this seems wasteful in modern eyes, the sanitary benefits should not be under-estimated (Hodge 1992, 307). Constant flow also meant there was not time for lead to leach into the water (Hodge 1981, 489). Vitruvius warns against the use of cisterns and tanks due to organisms growing in stagnant water, instead recommending aqueducts (Vitruvius, book viii). While the aqueduct had replaced cisterns in general (Hodge 1992, 58; Laurence 1994, 44),

water tanks may have been in use to complement the aqueduct (Hodge 1996, 273).

The tanks used for storage include castellum, lead lined tanks at the tops of towers, placed within the public water supply system. The lead lining no longer exists (Hodge 1996, 271) so it is not possible to assess any hard water accretion. Hodge notes how quickly (less than 10 minutes) a tank could empty if just one of the six exit pipes were used and how little is known about the tanks' supply (1996, 271-2). The tanks may have been for storage within a segmented tap-controlled system (Hodge 1996, 273). This appears to contradict knowing that lead was only safe if the water was constantly flowing, but it is not known how long the water was stationary for or if it was definitely stationary at all. Tanks atop water towers would have improved supply and pressure further down the system. This 'buffering' was already used in Roman textile manufacturing (Hopkins 2007, 216-217). Buffering through water towers and reservoirs is used in mains water supply in the UK today to maintain water pressure (Thames Water 2015 online, Ofwat 2016 online).

In situations where water was temporarily stagnant within lead containers, intangible learned behaviour might also have prevented lead poisoning. Safety measures for using water drawn through lead pipes even survived into modern Britain: it is usual in an older house with lead pipes to run water from the tap before drinking it, especially first thing in the morning: the 'first draw'. It was believed that the water would taste fresher and contain fewer contaminants. This behaviour and reasoning has been described since at least the mid-19th century (Blake 1956, cited by Hodge 1981, 489). Hodge grew up in a house doing this (Hodge 1981, 488). The author was doing likewise into the 21st century. Of interest is how quickly behaviour is lost: the author's contemporaries felt running the water was wasteful, applying a 21st century mindset (where water customers pay by metered quantity used) to a 19th century situation. When attempting to understand a 'dangerous' system, an allowance should thus be made for user's behaviour, as the dangers may be known and prevented by appropriate measures.

It has been concluded (e.g. Hodge 1992; Hopkins 2007) that despite the use of lead pipes due to the hard water, the design of the supply and the learned behaviour, the water contained little or no lead as it reached the dyeing workshops. However, the dyeing kettles were constructed from lead (Moeller 1976, 35-39; Monteix and Pernot 2005). Madder dye liquor is acidic (Kania *et al.* 2014; this volume) so an unknown quantity of lead would have leached into the dye liquor,

affecting the resultant material colour. Acidity may have had a multiplying effect: an increase would cause an increase in lead contamination, increasing the possible effects on the dye and fabric as the lead acts as a mordant. The effects of this are unknown, but merit further study.

Rebuking conventional wisdom

Until the mid-20th century it was believed that Pompeii's inhabitants were in constant danger of lead poisoning. This idea was challenged using modern engineering to reinterpret evidence from Pompeii. The conclusion was that Pompeii's water supply contained little or no lead due to an awareness of the dangers and the design of the system, which relied on continual movement of water that contained calcium deposits (e.g. Hodge 1992; Hopkins 2007). The water contained within the pipes simultaneously moved sufficiently fast to prevent prolonged leaching from the lead while the calcium deposits coated exposed lead, rendering the pipes safe to drink from.

New findings now show that despite the design of the system and the presence of calcium deposits, Pompeii's water supply had contained lead. Analysis of the polar ice caps shows lead in the atmosphere contemporaneously to Pompeii (Keenan-Jones 2011). Analysis of Pompeii's skeletons show lead in the bones. The sinter coating water pipes contains lead (Keenan-Jones 2011), (unsurprising in lead pipes!). By itself this does not indicate there was lead in the water of Pompeii – atmospheric or skeletal lead could come from other sources, and lead in the sinter may not leach into the water or may be negligible. However, recent analysis of Pompeii's water supply also showed lead (Keenan *et al.* 2011). Whenever pipes were renewed with fresh lead, a quantity leached into the water before the pipe calcified. This meant there was lead in the water, even if it was at a low but unpredictable concentration (Keenan-Jones 2011). It is still of note that lead poisoning was not recorded, suggesting that lead contamination through water was either not present, not recognised or was not viewed as problematic.

Experiments undertaken at the European Textile Forum in 2012 explored the effects of kettle materials on water content and dyeing outcome when dyeing with madder or birch (see [Chapter 8](#)). Of materials available in Pompeii, iron and copper adversely affected the dyeing result, while lead, particularly oxidised lead, was the 'neutral' kettle, causing a brighter, clearer colour similar to that of the inert control. It is unknown whether this was caused by contact with lead

or by lead leaching into the dye liquor. Dyers were exposed to lead through the water supply, apparatus and possibly the dye liquor. Vitruvius only mentioning lead workers becoming unwell suggests dyers were not overtly affected.

During this study, tap water has been used for the experiments undertaken in Bradford in Great Britain and in Mayen in Germany. This is because, in comparison to rain, distilled or de-ionised water, it was of known content and continuously available. The lead content of each water supply was negligible.

Water supply to dye works

In his *Ten Books of Architecture* Vitruvius also wrote of the ideal construction of a water distribution system within a city. This appears to be a textbook showing how things were done, but is actually a statement of how things *should* be done. Vitruvius wrote based on real structures, but could deviate, so should not be taken as a faithful report of Roman building practice (after Plommer 1973; Hodge 1992, 15). Classicists and archaeologists are tempted to cite the works of Vitruvius rather than fully investigate and understand the principles he described:

The temptation, when a problem arose, was always to reach for the volume of Vitruvius, conveniently to hand, rather than go to the site, often inconveniently distant, to look at the actual remains, much less, to cross the quad to that, psychologically at least, even more distant ultima Thule, the Faculty of Engineering. (Hodge 1992, 15-16)

Any author quoting Vitruvius without explaining what they take him to mean should be regarded with caution.

Hodge cites the example of Callebut (1973 in Hodge 1992, 281-284), who is reported to have described Vitruvius' and Pompeii's distribution systems as similar. They are not: Vitruvius says to divide the water into three, then channel the overflow of two (the baths and the private houses) into the central one (the public fountains) (Vitruvius book viii chap. vi 1-2), but in Pompeii prioritisation occurs before division. By Vitruvius' method all three divisions gain a supply. In Pompeii the private channel will only receive a supply when the other two channels are already full (Hodge 1992, 284). This prioritisation means it was in the interest of the dyeing workshops to rely on a public rather than private supply. Workshops Vi4 and Vi5 did this, and it appears other workshops did too.

The survey undertaken in 2002 (Hopkins 2007, 75-98) showed the source of water most convenient to each dye works. Dye works require substantial quantities from reliable supplies. Public sources were more reliable than smaller, temporary cisterns, which may have been used as a 'buffer', but also required reliable refilling, such as from a fountain. Public fountains were prioritised in supply, so were the last to fail should the supply be interrupted. Business is pragmatic: water would come from the cheapest, easiest source. The geographical relationship between fountains and dye works was determined to see if this source was practical.

Following the earthquake in AD 62, the dye works moved from industrial to residential areas of Pompeii. This may be due to social upheaval, such as redistribution of property when some wills could not be realised. But as the residential areas were first to be re-connected to the aqueduct water supply, there was an economic advantage to moving: dyeing businesses could restart quicker.

Each dye works was within 50 m of a public fountain, confirmed during the 2002 survey of the remains (Fig. 9.4). It has been asserted that each public fountain was at the junction of roads (Laurence, 1994, 44). It is possible that Laurence only recorded larger fountains, comprising both a fountainhead and trough. A map of standpipes appears to show these were also at a distance from dye works (Richardson, 1988:52). These assertions are not correct as two dye works (Vi4 and Vi5) were located adjacent to a public fountain (Fig. 9.5). This shows the necessity of assessing the water supply for each dyeing workshop firsthand and not relying on others' surveys. A further complicating factor is that supply or drainage pipes may remain hidden: excavation has shown some dye works to have channels or plumbing, of unknown purpose, below the current floor level (Borgard *et al.* 2003). Excavation shows that fullonicae could have internal pipework supplying water to fullers' tanks or internal fountains (Flohr 2011). The presence of private plumbing could still be used to impress and served as status symbol (Flohr 2011), even if private supplies failed before public supplies. Private supplies required expense and additional plumbing: public supplies could be accessed quickly and cheaply by bucket or siphon.



Fig. 9.4. Location of dyeing apparatus, dyeing workshops and water fountains in Pompeii (after Laurence 1994). Each dye works was within 50 m of a public fountain, confirmed during the 2002 survey of the remains. Light grey: fountain; mid-grey: dye works; dark grey: discounted, dye works



Fig. 9.5. Fountain outside dye work Vi4. Vi5 is adjacent (to the right). It may be supposed, that the dye works Vi4 and. Vi5 obtained, water from this fountain. This fountain is not shown on Laurence's (1994) map

Storage in the dye works

Vitruvius warned against using cisterns due to the stored water becoming contaminated through living creatures. Despite this, cisterns were used to store rainwater collected from roofs (Keenan-Jones 2005). The survey confirmed that this was both in properties in general and in dyeing workshops (Hopkins 2007).

Moeller identified dyeing and water storage apparatus (tanks, dolia)

in his survey (Moeller 1976, 29-56). He may be inaccurate due to not knowing the water quantities required. Equipment lost over time also misleads findings. A dolium is identified in property I viii 19. Dolia may have been used for cold dyeing or rinsing, instead of water storage. The dolium in property I viii 19 shows no signs of staining through dyes, but any stains may have been lost. Tanks within I viii 19 may have been used for storage or cleaning. A 'dolium base' was identified in Vi4 in the 2002 survey, but the space required meant it could not have been used where it was found. It was concluded to be the base of another artefact, since lost ([Fig. 9.6](#)).

Of interest to understanding storage are the digital maps of Pompeii. As late as 1998 there was still no complete survey of Pompeii (Fulford and Wallace-Hadrill, 1998) – each part of Pompeii had been recorded during separate surveys but there was no single combined plan. In 2002, at the start of this study, widespread digital camera and mobile phone use was in its infancy. The first complete overview of Pompeii was a digital map, copyright of the superintendent of Pompeii (2004), based on a satellite photograph of the city. This led to questions such as how multi-storied buildings should be depicted (after Burnside 1979, 68). The advent of the satellite image should have meant that the resultant digital map was accurate and could be used as the basis of understanding structures within the city: even allowing for warping (Burnside 1979,68) each feature should be discernible and relate to internal features within buildings and to each building's wider context (Brophy and Cowley 2005, 123).



Fig. 9.6. The dolium in I viii 19

When compared to the original photo and earlier piecemeal plans there were also questions regarding the accuracy of the digital plan. Not only had doors and walls moved, but items shown on plans from 1970s had disappeared (Hopkins 2007). This included a tank shown in property IX iii 2, which could have been used to store water as an industrial buffer should the public supply fail.



Fig. 9.7. The 'dolium' base in Vi4. The space required means that it could not have been a dolium base or used in this location. It was concluded to be the base of another artefact, since lost (see [Table 9.1](#))

It highlighted the difficulty in what should be recorded: what exists now on a photograph (the only provable version) or what is known to have existed to prevent the loss of earlier remains. The loss of the tank from the ground, photo and digital image mean it is not possible to assess if one had really existed and its structure. Moving walls and doors, or failing to depict a basement or second floor, affects the understanding of water acquisition, storage of consumables, and disposal of waste products such as heat, water and exhaust gases. Every part of the dyeing process ([Fig. 9.1](#)) would be affected. This highlights the importance of surveying the site and accessing historic plans before forming conclusions.

Water use within a dye works

Filling and using a dyeing apparatus may result in spillage, so it is not possible to say how much water was actually used in a dye works. But, assuming that the dyeing cycle was 24 hours, a figure derived from using the experimental replica and allowing it to cool naturally after use, apparatus would have been filled and emptied once a day (Hopkins 2007, 64-67, 193-199), so an estimation of a minimum amount of the water used if all of the apparatus were to be used can be made.

It shall be assumed that the dyeing kettles were filled to the brim. It is extremely unlikely that they were, but calculating using the full volume allows an estimate of the maximum quantity of water required if the apparatus were to be used once per day. The actual depth used during dyeing is unknown, but the full volumes of the kettles can be calculated from standing remains. The purpose is to give a figure. As yet no calculation of the water required by the dyeing industry has been made, and so there is yet no understanding of whether there was sufficient water to supply the industry. It is possible that insufficient water supply could have limited dyeing output. It is only by understanding the magnitude of the water required for the industry that it is possible to begin to understand whether water supply could have affected its operation.

The closest modern equivalent to a Roman fleece is a Shetland, weighing approximately 2 kg (Ryder 1990). Approximately 90 litres of water was required per fleece according to Storey (1978, 66) so it is possible to calculate how many 'fleece-worths' of water a given kettle

could hold. It can be presumed that the quantity used per fleece was 90 litres as substantially more would cause a weakened solution while less would not allow the fleece free movement in the dye liquor. An additional 10 cm water depth allows an extra fleece to be dyed in the larger 900 litre kettles, so to improve confidence in calculation only the full volume of the kettle shall be used. Storey’s recipe gives a range of 80-100 litres, but this involves conversion of two quantities from imperial to metric measure (Storey 1978, 66). The number of fleeces a kettle could hold can be estimated, within a range (Hopkins *et al.* 2005).

The conjoined apparatus in property IX iii 2 were amended during the modern era: at some point in the last 200 years they were consolidated and restored through the application of cement and matching rubble. This action has ensured that they have remained preserved into the modern era. Unfortunately the errors contained within the restoration were only discovered following an ergonomic assessment of the apparatus which discovered that they were now at least 20 cm taller than they were in antiquity and would have been unusable in their current state (Hopkins 2007, 82, 125-126). As the original height cannot be judged with absolute certainty, it is necessary to calculate two volumes for these apparatus: amended and unamended. The volumes of the apparatus and the daily and annual water requirement for the dye works of the city are shown in [Table 9.1](#).

Table 9.1. Volumes of the apparatus and the daily and annual water requirement for the dye works of the city. Light grey: minimum value. Mid grey: approximate value. Dark grey: maximum value.

I viii 19	1	0.98	0.75	0.51	384.62		
I viii 19	2	0.84	0.55	0.54	299.20		
I viii 19	3	0.74	0.43	0.63	270.90		
I viii 19	5	0.97	0.74	0.75	554.13		
Total						1508.85	479,814.3
V i 4	4	0.97	0.74	0.8	591.07		
V i 4	5	0.61	0.29	0.52	151.94		
V i 4	6	1.2	1.13	0.8	904.61		
V i 4	7	0.74	0.43	0.78	335.40		
V i 4	8	1.2	1.13	0.81	915.92		
Total						2898.94	921,862.92
V i 5	1	0.95	0.71	0.6	425.21		
V i 5	2	0.5	0.20	0.91	178.64		
V i 5	3	0.99	0.77	0.68	523.34		
V i 5	4	0.85	0.57	0.69	391.47		
Total						1518.66	482,933.88
VII ii 11	1	1.06	0.88	0.69	608.80		
VII ii 11	2	1.06	0.88	0.74	652.91		
VII ii 11	3	0.96	0.72	0.6	434.21		
VII ii 11	4	0.76	0.45	0.56	253.99		
VII ii 11	5	0.5	0.20	0.43	84.41		
VII ii 11	6	0.86	0.58	0.54	313.62		
VII ii 11	7	0.55	0.24	0.55	130.65		
VII ii 11	8	0.99	0.77	0.38	292.46		
VII ii 11	9	0.94	0.70	0.55	381.62		
Total						3152.67	1,002,549.06
VII xiv 17	1	0.68	0.36	0.5	181.55		
VII xiv 17	2	1.17	1.07	0.65	698.70		
VII xiv 17	3	1	0.79	0.76	596.79		
VII xiv 17	4	0.99	0.77	0.68	523.34		
VII xiv 17	5	0.6	0.28	0.43	121.56		
VII xiv 17	6	1.09	0.93	0.48	447.82		
VII xiv 17	7	0.68	0.36	0.51	185.18		
VII xiv 17	8	0.95	0.71	0.63	446.47		
VII xiv 17	9	0.51	0.20	0.43	87.8247		
VII xiv 17	10	0.94	0.70	0.6	416.31		
Total						3705.545	1,178,363.2146
IX iii 2		0.73	0.42	1.33 or 1.13	556.55 or 472.86		
IX iii 2		0.83	0.54	1.3 or 1.1	703.25 or 594		
IX iii 2		0.9	0.64	1.35 or 1.15	858.67 or 736		
Total						2118.47 or 1802.86	673,673.46 or 573,309.48
City total						14,903.13 or 14,587.52	4,739,196.8346 or 4,638,831

The bases of the kettles are circles. The area of a circle is $\pi \times \text{radius}^2$.

The volume of a cylinder is therefore $\pi \times \text{radius}^2 \times \text{height}$.

Note: Volume of apparatus 2, Property I viii 19, was derived from

circumference of the kettle (2.64 m), not the height and diameter, due to extensive damage.

$$\text{Circumference}/\pi = \text{Diameter } 2.64 \text{ m}/3.141 = 0.84 \text{ m}$$

The calculation of the water used in dyeing assumes that every apparatus was in use and was filled only once a day. The individual quantity required for each apparatus and the combined quantity required to fill every kettle in a specific workshop are shown in Table 7.1. If each apparatus were filled to the brim and no spillage occurred, the combined daily total of water required to fill every dyeing kettle in Pompeii was 14,588-14,903 litres. Assuming that there were 318 working days in Pompeii, the annual water quantity required was 4,638,831-4,739,197 litres. That would mean that the dyeing industry, if dyeing just with madder, would use in excess of 4500 tonnes of water annually. However, madder is a dye that requires the material to be pre-mordanted. To do this it must be treated in a heated bath prior to dyeing, possibly in the same apparatus that could then be used for dyeing. If pre-mordanting and dyeing took place on the same day, the water consumption would double, so that 9000-10,000 tonnes of water could have been used annually. If dyeing and mordanting took place in discrete batches on alternate days, allowing the apparatus to be cleaned in between, the water consumption would be the same but the production capacity of the dyeing industry would be halved. A vat dye such as woad would not have required pre-mordanting so less time and water would be required. Following dyeing the material would require rinsing, which would use further water in copious amounts. It is not possible to predict the quantity of water required as this depends on unpredictable variables, although madder, for instance, will require more water than birch as it is a ground root, and the particles are harder to rinse out (pers. comm. Ringenberg 2018).

To understand if sufficient water was available to operate all dyeing apparatus at full capacity, it would be necessary to quantify the supply that reached Pompeii. The amount is currently unknown, but it is known that it was seasonally affected. Quantifying water supply in the Roman world is difficult as, although the route and cross section of the supply may be known, velocity is not (e.g Hodge 1992; Keenan-Jones 2005; Keenan-Jones *et al.* 2015). The aim of this calculation is to give a wider appreciation of the role of the dyeing industry in the wider fabric of the city and to allow the context of the water requirement to be understood when the water supply eventually becomes known.

It is presumptuous to assume that every textile item was dyed. The majority were not (Hopkins 2007, 31). However, soft furnishings, such as curtains, were wholly dyed or made from dyed fleece or thread. When the requirements of the city, which would include the furnishing of public and religious buildings, are fully considered and compared with the maximum production capacity of Pompeii as estimated in the study mentioned above (8 kg per person in Pompeii) it may be seen that the production of dyed textile must have been limited (Hopkins 2007). Furthermore, the quantity of textile that was re-dyed is unknown but re-dyeing would have reduced the capability to produce new dyed material by competing with the same resources.

It is possible that differing recipes would have required different quantities of water or that it may not have just been whole fleeces that were dyed. There are parts of the fleece that it is wasteful to dye as it is of insufficient quality to be used for any purpose that would require it to be dyed. Also, as demonstrated in person at Textilforum 2009 by Sabine Ringenberg, it is possible to re-use the dye liquor to produce three times as much dyed material from one batch as a single dyeing would produce, thereby tripling the dyeing output without significantly increasing the resources used (Hopkins 2013a; 2013b; 2013c). The use of a 'fleece worth' was to give a comparable quantity when understanding the capabilities of the industrial equipment.

The quantity of water calculated above would be the requirement if every dyeing apparatus were operating once per day and filled to the brim at full capacity. It is possible that they were not. It is also possible that the dyeing liquor was re-used, thereby increasing dyeing output with or without increased water use (Hopkins 2013a; 2013b; 2013c).

Disposal of water

Although each dyeing apparatus was of the same design, they differed in size between 90 litres and 900 litres capacity. The workshops contained up to ten dyeing apparatus. This means that each workshop needed to dispose of 1.5-3.7 tonnes of water daily if every apparatus had been used and was emptied daily. It is possible that this was simply disposed of in the street. This is not as far-fetched as it sounds. As the method of water supply in Pompeii was an aqueduct, the fountains had each been designed to 'overflow' as the water could never be shut off (Hodge 1992, 335). Hodge notes that the raised kerbstones and stepping stones (*pondera*) indicate a need for a raised

walkway due to the constant flow of water through the street, but felt that the height of 0.5-0.6m may be excessive (Hodge 1992, 335-336). However, Pompeii is in an exposed location and subject to sudden heavy rainstorms. The torrents that rush through the streets, deepening as streams intersect, reach up to 0.5 m, as witnessed by the author during the 2002 survey and subsequent visitors (Fig. 9.8). It is possible that any dye liquor disposed of in the street would meet the fountain overflow and rainwater, and be washed away. Fullonicae had pipes that led through walls to dispose of waste water into open streets (Keenan-Jones 2005; Flohr 2008) so disposal of waste water from dyeing into the street is not unlikely. As Flohr notes ‘care was taken to organise waste disposal even in smaller workshops’.



Fig. 9.8 Rain run-off in the streets showing the pondera are of correct height. Showing Sera Baker, Nottingham University (photos: Sera. Baker)

The ‘excessive’ height of the *pondera* are reminiscent of Hodge’s question of why the capacity of the pipes leaving the Castellum in Pompeii are so much larger than the quantity of water that would flow through them from the aqueduct (Hodge 1996). Hodge concludes that it indicates timed rationing of water, but also notes that in times of flood the aqueduct may carry more water than would be contained just within the central channel (Hodge 1996, 263). It is possible that the Castellum may have been ‘over-engineered’, built to ensure that any increased demand for capacity in the future is already allowed for. This would mean that any unpredictable temporary increases in water supply, such as during a flash flood higher up the system, can be contained. But it also allows for future growth: it is difficult to add

capacity once an expensive or complicated system is already in place, a theory used later with great effect by Bazalgette when designing London's Victorian sewers which are still in use today (Science Museum 2016 online).

The dyeing process would have led to excess water leaving the apparatus and wetting the floor. This may have occurred during filling of the apparatus, dyeing, removing the fleece or emptying of the apparatus. There is further evidence that the water simply ran over the floors and out into the street: grooves had been cut into the doorsills of Property I viii 19 and Vi4 to allow this flow of water (Figs 9.9-9.11). Properties I viii 19 and VII xiv 17 abutted enclosed backstreets in which flowing water would not have excited comment, Vi4 and Vi5 abutted a road with free-flowing water from a fountain and property VII ii 11 and IX iii 2 abutted a main road. The enclosed backstreets contained a central groove in which water would have collected. It is therefore probable that dye liquor and waste water was disposed of into the street. The water would have been diluted and disposed of through addition to the waste water from the fountains in the main streets.



Fig. 9.9. Slice cut in doorstep, property I viii 19, allowing drainage into sidestreet. Horizontal measure: 0.2 m



Fig. 9.10. Photograph showing groove cut into doorstep and the backstreet into which water drained, property I viii 19. Vertical measure: 1 m. Horizontal measure: 0.2 m.



Fig. 9.11. Grooves left-right cut into doorstep of Vi5 to allow drainage. (Single groove top-bottom of the photograph was for the edge of the door shutter)

Conclusions

The water supplied to the dye works of Pompeii was hard water and contained minimal lead, temporarily increased when new pipework was installed. It is possible that lead may have leached into the dye liquor from the kettle during dyeing. A substantial quantity of water was used by the dyeing industry, but it was only a fraction of that

supplied to the city as a whole. The dye liquor was disposed of into the streets where it was removed through the effects of the ever-flowing water supply. The dyeing industry was a well-adapted part of city life.

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